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RESISTANCE SETTINGS FOR ANAEROBIC POWER TESTING

by

© JOHN A. EVANS

A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES
AND RESEARCH IN PARTIAL FULFILMENT OF THE
REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE

FACULTY OF PHYSICAL EDUCATION

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THE UNIVERSITY OF ALBERTA

FACULTY OF GRADUATE STUDIES AND RESEARCH

The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research, for acceptance, a thesis entitled RESISTANCE SETTINGS FOR ANAEROBIC POWER TESTING submitted by JOHN A. EVANS in partial fulfilment of the requirements for the degree of Master of Science in Physical Education.

W H Cottle

Supervisor

Richard Routledge

Quinney

Date May 27, 1980

Dedicated with love

to Valerie, Tim and Allison

ABSTRACT

This study was designed to investigate constant resistance (force) settings for 30 s tests of maximal anaerobic power on a modified Monark bicycle ergometer. Twelve active to highly trained adult males had multitrial determinations at various resistance settings to obtain the true force to elicit maximal power output in 30 s (FMPO). True maximal power output (MPO30s) exceeded the power output obtained with the weight-relative Wingate protocol. Retest of MPO30s at FMPO proved reliable ($r = 0.962$). Regression equations were developed from (a) a combination of body weight and leg volume: FMPO,kp = -0.4914 - 0.2151 (WT,kg) + 2.1124(LEGV,L) where $R = 0.873$, and (b) power output at 5.0 kp to predict FMPO: FMPO,kp = -9.0166 + 0.0291(PO5kp,W) where $R = 0.774$, to obviate multitrial tests. The former (anthropometric) method was used to obtain power outputs on the 1980 Canadian Olympic Hockey Team of 775.1 ± 74.6 W (9.58 ± 0.78 W/kg). An optimal combination of resistance setting and pedalling speed seems necessary to elicit true maximal power output for an individual in a 30 s ergometer test.

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I. H. S.

Neither be called masters,
for you have one master,
the Christ.

MATTHEW 23:10

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INTRODUCTION

Physical activities, particularly athletic events, are characterized as either aerobic or anaerobic and static or dynamic in nature. Although static components, such as stabilization of joints or trunk, occur in athletic endeavours, dynamic components of moving the limbs or the total body comprise the effectual part. Movement means the expenditure of energy to allow work to be done in exerting a force through a distance. Power, the rate of doing mechanical work, or the intensity of the physiological response to the work, is implied in all movement. Varying factors of movement, such as force, speed, distance or time, will alter the physiological response to the work of movement, leading to utilization of different biochemical pathways, anaerobic or aerobic, to sustain the effort. Anaerobic power, when tested as an element of fitness, is the subject's ability to do as much work as possible in a fixed, brief period of time.

The relationships between internal biochemical events and associated external production of muscular work have developed over the last century. In 1841, Berzelius noted that the muscle of deer, run to exhaustion, showed elevated lactate levels over resting values (Davies, 1971). The relationship of the formation of lactic acid and muscle energy release in humans involved in exercise was investigated by A. V. Hill, Long and Lupton (1924). The concept of "oxygen debt" was thought to be linked to lactate production. Margaria, Edwards and Dill (1933) partitioned oxygen debt in exercise into an "alactacid" portion, as initial fast component of $\dot{V}O_2$ recovery after exercise not due to lactate removal, and a slow component of recovery associated with lactate accumulated during exercise. Huckabee (1958) however concluded that a single exponential recovery of $\dot{V}O_2$ occurred instead of a double exponential expression. There supposedly was no alactacid portion. They attributed the debt to a lack of oxygen to oxidize accumulated lactate, which in turn was due to tissue hypoxia. Because lactate could be increased in the blood by several non-hypoxic measures, he introduced the idea of "excess lactate", the portion of lactic acid attributable to tissue hypoxia. Glycolytic involvement in production of energy for muscular work becomes sizeable after severe depletion of high-energy phosphagen stores just before 1 minute of heavy work (Saltin, 1973) and aerobic involvement after 2 minutes of exercise (Astrand and Rodahl, 1970). The investigation of biochemical causality in muscular power continues.

Measurement of mechanical power of human subjects has been made in laboratories for some 60 years. For example, D.A. Sargent (1921) incorporated factors of body height, weight and vertical jump height into a physical efficiency index. Thus body dimensions, "mechanical advantage", performance, "strength speed and energy" have been concepts in power testing for a long time. L.W. Sargent (1924) qualified the expression of results of the Sargent jump to divide the "total work of the jump" by the body weight and realized "flabbiness and fat, slowness, poor coordination and lack of driving power and interest are penalized by the actual results." The importance of speed of execution of the jump and the suggestion of rate of work in the jump as a power measure were qualified. Because strength was poorly correlated with jump height, strength alone was not the only factor in the test but "muscular sense, skill and speed" contributed.

The study of human power had its origins not only in athletics but in aeronautics also. Dr. Brustman, a German medical doctor and sports physician, entered man-powered flight contests in 1929 in an ornithopter, built around and above a bicycle, "high on the wheels, flapping the wings like a newly hatched chicken." To exemplify possibilities of human power levels being adequate for such efforts, Brustman postulated the hyperbolic power function (power/duration plot) with asymptotes of maximum instantaneous power of approximately 1800 W and enduring power of 190 W (Lippisch, 1960), a somewhat more elevating contribution to the science of motion. Similar power outputs of 220-240 W occurred in a recently successful man-powered flight across the English Channel (Allen, 1979). Hutto (1938) explored the joint contribution of strength and velocity factors in boys' track and field events by factor analysis. He concluded both factors work together as a single component of athletic power. The concurrent evidence given by Hill (1938) of a hyperbolic force-velocity relationship in isolated muscle preparations confirmed the physiological internal and performance-oriented external importance of human power as a combined function of force and velocity of movement.

Current investigations of anaerobic power have revolved around impulse and high power tests. Performance-oriented impulse tests included the standing broad jump, vertical jump and stair run (Margaria, Aghemo and Rovelli, 1966), lasting less than one second. Mechanical tests of high power in the laboratory have usually involved all-out bicycle trials with a fixed resistance (force) setting and an all-out pedalling cadence (velocity). Cumming (1973) employed a test lasting 30 s (30 s time frame) for such an anaerobic test on children.

Subsequently Ayalon, Inbar and Bar-Or (1974) used the 30 s test duration and a force setting relative to the individual subject's anthropometric dimension (F = 0.075 kp/kg body weight, personal communication with O. Bar-Or, 1977) to test anaerobic power. Campbell, Bonen, Kirby and Belcastro (1979) similarly used a force setting relative to a previously-tested physiological functioning (F = 1.5 x F at $\dot{V}O_2$max with 60 rpm cadence).

Anaerobic athletic events are as numerous as aerobic ones but the measurement of anaerobic power seems much less established. With awareness of the importance of the force-velocity relationship in various muscle studies in vivo and in vitro and the need for an anaerobic power test of a sufficient duration to tax phosphagen-splitting and glycolytic mechanisms, the author undertook the study to determine appropriate resistance settings for such a measurement on the bicycle ergometer.

Statement of the Problem

The purpose of this study was to improve an existing anaerobic power test for active to highly trained subjects by developing methods of determining resistance settings on a bicycle ergometer to elicit maximal power output on a 30 s all-out protocol. The study examines the following questions:

1. Do the power outputs of existing protocols elicit true maximum power output (MPO)?
2. Is the determination of MPO reliable?
3. Is there an expendient method of estimating the force setting that elicits MPO (FMPO) without

numerous test trials involved in developing the complete power curve for an individual subject?

4. What are possible power outputs for active to highly anaerobically trained athletes?

Limitations

The following limitations may have had an effect on this study:

- there was a limited number of subjects available (n = 12).
- a heterogeneous group of active through to highly trained subjects was sought but 8 were active and 4 were highly trained.
- the study is limited to the mechanical development of power on the bicycle ergometer with no invasive measurements.

Experimental Error

One source of error identified was some hysteresis in calibration of force setting from 8.0 kp to 10.0 kp.

Delimitations

This study involved active to highly trained male adults. The applicability to other sex, age and fitness groups requires further investigation. Cross validation is necessary in a future study. The power of the leg extensor/flexor group is studied. Other similar tests could be developed for other muscle groups.

Definitions of Terms

Work: Work on a body by a force is equal to the displacement of the body multiplied by the component of the force in the direction of the displacement.

$$W = F (\cos \theta) d$$

where W = work

F = force applied

d = displacement

and θ = angle of force to direction of displacement

Power: Power can be defined as the rate of doing work.

$$\text{Power} = \frac{\text{Work}}{\text{Time}}$$

$$= \frac{\text{Force x distance}}{\text{time}}$$

$$= \text{force x velocity}$$

Whether the work is done on the body as climbing stairs or in moving an object external to the body such as putting the shot, for a short or long duration, the power used to do the work is a function of time, distance and force:

$$P = F \lim_{\Delta t \to 0} \frac{d}{\Delta t} \qquad \text{(Kelley, 1971)}$$

Δt is reduced to a vanishingly small interval in impulse physical actions. The d is reduced to zero in isometric contractions and no classical work is performed. Force and its analogues, resistance or weight, vary greatly with the particular type of activity. A functional definition of power includes the relative maximum load that can be moved at a maximum speed for either a low, medium or high number of repetitions; that is high power,

power and power endurance (Edington and Edgerton, 1976). The full spectrum of various possible loads and speeds, including those other than maximum, for the full spectrum of durations from short impulse, less than one second, to long-term capacity events, lasting possibly hours or days, allows discussion of power in terms of instantaneous relative intensity and rate of doing work.

Capacity: The relationship between intensity (power) and capacity of energy for work is expressed by the following formula:

$$C = \int_{ta}^{to} I\, dt,$$

where C is the capacity, ta is the time of start, to is the time to exhaustion, dt is the change of time and I is the intensity (Ikai, 1974). The concept when applied to man usually applies to the increase of cost of work over and above that at rest.

Energy: A body is said to possess energy if it is capable of doing work.

At a cellular level, power is determined by the rate at which energy is released from the cells. The energy release processes are categorized as anaerobic or aerobic, according to the contribution of oxygen to the process. The human body transforms the chemical energy in foodstuffs, mainly glucose, glycogen and fatty acids, into adenosine triphosphate (ATP). This chemical form of energy is used in muscle contraction that moves objects, thus transforming chemical energy into mechanical energy. Power is the rate of physiological energy turnover (Mathews and Fox, 1976). The exercising body utilizes the pathways of anaerobic metabolism when the work output exceeds that which can be performed by means of oxidative pathways alone.

Anaerobic capacity consists of the energy that could be released without the availability and/or involvement of an appropriate amount of oxygen (Knuttgen, 1969). A person's anaerobic capacity allows him to perform physical activity while holding one's breath to perform a level of activity which demands energy in excess of his aerobic capacity for some minutes. It connotes the idea of sustaining activity over a period of time at a particular intensity or power level, or the integrated capacity over a period of time for a varying intensity function. The level of intensity need not be maximal to tax a person's capacity. Duration need not be maximal for sense to be made out of the capacity function,

Power x Time = Work = Energy.

The area under the power-time curve for a non-maximal duration would be the work or energy needed for accomplishing the task, regardless of intensity (power) or duration involved.

Anaerobic power has been said to determine the amount of work possible in an all-out effort for a period of approximately 45 seconds through anaerobic release mechanisms (Larson, 1974). Anaerobic power for our purposes shall be defined as that contribution of anaerobic mechanisms to the total power output. Maximal anaerobic power is the instantaneous maximal anaerobic release contribution to the overall power outout of the individual. Anaerobic power has been classified into various types; oxygen debt, lactic acid in the blood and mechanical power (Larson, 1974). Mechanical power is often hard to evaluate in complicated physical or athletic events. Therefore we can consider gross performance measures when mechanical measures are difficult to make.

Total work capacity and total power are meaningful ideas. Total work capacity would be the sum of the capacities for aerobic and anaerobic work for a period of time to exhaustion. Duration in such events as marathon running and day-long cross-country skiing would then be reflected in metabolic capacity. Duration in shorter events could comprise of a larger anaerobic contribution. Similarly total power and relative anaerobic and aerobic contributions has become important in the determination of anaerobic threshold, the onset point of metabolic acidosis in which accumulating acidic substances or decreasing basic substances results in increasing alveolar ventilation (Davis, Vodak, Wilmore and Vodak, 1976). At this point aerobic contributions to total power are inadequate in supplying the energy required for the increased demands of sustained athletic performance. Lactate accumulates, respiratory measures change.

Bicycle ergometer: a stationary bicycle designed to load an exercising individual, in order that mechanical power output can be calculated. Manipulation of frequency of pedalling (speed in rpm) or frictional resistance (force in kp) results in change of power output.

Power curve: the power to force relationship, approximately hyperbolic in shape graphically. It is specific in force and power for each subject. It is determined by applying larger (constant) frictional resistance settings on the ergometer for successive 30 s trials until power outputs decrease; then a homing procedure is used to obtain the maximal power output within ¼ or ½ kp. Thus determination of the power curve is iterative rather than randomized.

Maximal power output (MPO): the highest possible rate of doing mechanical work by an individual subject. Two measures of MPO are considered in this thesis. One is the average of 6 x 5 s power outputs for a single trial of 30 s duration (MPO30s), referred to as anaerobic power because it depends on phosphagen-splitting and glycolytis at high intensity. The other is the highest power output of the 6-5 s values, only rarely not the first in the 30 s sequence, is the peak power output (MPO5s) and it mainly reflects phosphagen-splitting. When referring to the experimental group of this study, MPO refers to the peak power on the individual subject's power curve. That is, the actual MPO30s accepted as criterion. When applying the prediction equation to approximate resistance applied during a single-trial power test, MPO30s is estimated. It is a single point on the power curve only, estimated to be maximal. The term maximal has referred to the intensity of power output at $\dot{V}O_2$max in many studies in the literature. Similarly, submaximal has referred to intensities of exercise below $\dot{V}O_2$max and supramaximal, described above. In this study maximal refers to the highest intensity possible for an individual in the time span quoted, such as MPO30s. Submaximal refers to values less than the highest possible for the equivalent time span.

Force to elicit MPO (FMPO): the force or resistance setting (kp) on the power curve that stimulates MPO30s. (Similar to MPO30s, FMPO for the experimental group refers to the actual FMPO that is accepted as a criterion.)

The Wingate force setting (FWIN): a relative resistance setting (kp) according to the formula devised at the Wingate Institute, Israel:

$$F = 0.075 \text{ kp/kg body weight (Bar-Or, 1977)}$$

The pretest power values (PO5kp, PO6kp): the power outputs (W) resulting from tests at absolute resistance settings at 5.0 and 6.0 kp, administered to all subjects at the start of the multi-trial determination of the power curve.

Absolute measures: the stimulus (for example, force setting for a power test) or response (for example, power output on a power test) of an individual for a power test with dimensions and units common to all subjects.

Relative measures: the stimulus or response of an individual subject in a fitness test with dimensions and units particular to the subject. A relative stimulus in a power test could be resistance levels set according to a previous performance score such as $\dot{V}O_2$max (Campbell et al., 1979) or precriterion tests, or according to anthropometric measures such as weight (Ayalon et al., 1974). An example of a relative response is power output per kg body weight (W/kg).

Oxygen deficit: represents the amount of oxygen at the onset of exercise less than the steady-state value needed to maintain work. It results from a lag in the time of adjustment of oxygen uptake to the exercise and contributes to the oxygen debt.

Oxygen debt: the quantity of oxygen taken up by the lungs during recovery from a period of exercise.

It is the amount above that necessary for an equivalent period of rest. It represents anaerobic metabolism and general elevated metabolic adjustments during the exercise. Knuttgen (1971) suggested some causes of oxygen debt were gluconeogenesis, resynthesis of depleted phosphagens and readjustment of electrolytic balance, body temperature sympathetic activity and hormonal levels.

Anaerobic threshold: the onset point of metabolic acidosis in a subject exercised with progressively increasing intensities of work. It is found at intensities found to elicit approximately 50 to 90% of maximum oxygen uptake.

Davis, Vodak, Wilmore and Kurtz (1976) examined the physiological indications of anaerobic threshold: disproportionate increases of expired minute volumes of air and CO_2 and of the fractional concentrations of oxygen and CO_2; increases of blood lactate concentration above the plateau of lactate concentrations found at intensities of exercise lower than anaerobic threshold. It is labelled by the power output on the bicycle ergometer, speed and grade on the treadmill or by the oxygen uptake, whatever the means of testing.

Anthropometric measures: leg measures were taken on a straight unweighted right leg with the subject in a standing position.

Leg length (LEGL): the distance (cm) from the greater trochanter of the hip to the laterial malleolus of the ankle.

Leg volume (LEGV): the volume (L) of water at 20°C displaced from a volumetric tank by the leg of the subject, immersed up to the ischial tuberosity and squared and straightened to the top edge of the tank.

Thigh girth (THIG): the circumference (cm) of the thigh taken at the midpoint between the greater trochanter and the head of the fibula.

Calf girth (CAFG): the circumference (cm) of the calf at its largest point.

Thigh skinfold (THISF): the vertical skinfold (mm) taken centrally and frontally on the thigh at the same point as THIG.

Calf skinfold (CAFSF): the vertical skinfold (mm) taken centrally and posteriorally on the calf at the same point as CAFG.

Pondural index (PI): an index of physique (Larson, 1974).

$$PI = \sqrt[3]{\text{Weight, kg}}/(\text{Height,cm}) \times 1000$$

% fat: the body composition of the subject as determined by densitometry or skinfold techniques (Larson, 1974).

Lean body mass (LBM): lean body mass, a subject's total body mass minus mass of fat (Larson, 1974).

FT fibre: fast twitch muscle fibre (synonyms - phasic, pale, fast glycolytic, type II fibre). They can be of glycolytic nature, IIb, or oxidative, IIa.

ST fibre: slow twitch muscle fibre (synonyms - tonic, dark, slow, oxidative type I fibre).

Delta efficiency: the instantaneous rather than overall efficiency of performing work - the caloric equivalent of increment of work performed above previous work rate divided by the increment in caloric output above that at the previous work rate, expressed as a percentage (Gaesser and Brooks, 1975).

REVIEW OF LITERATURE

When an animal performs a muscular action, it performs work which when experienced per unit time, is its power output. Its expression and measurement are modified and limited by a myriad of influential factors. The factors are surveyed in the following review for human beings with an emphasis on anaerobic power in all-out, short-duration tests on the bicycle ergometer. The myriad includes the subject's general disposition towards exercise, the subject's particular body structure, the action or function required, the means of measurement, the physiology and energetics of the action, the time course of the action, the environment in which the action is performed and other less evident factors.

General Subject Disposition

a) Heredity: Variability in the potential an individual person has to develop muscular power is probably genetically determined to a large extent. Komi and Karlsson (1979) have studied comprehensive tests of anthropometry, power (Margaria et al., 1966), maximum isometric leg force, EMG, aerobic power, peak lactate, muscle fibre composition and enzymes of monozygous and dizygous twins. They found a relationship between muscular power and fibre type distribution, which itself is mostly accounted for by the heredity variance. The genetic component of impulse power tested explained a large portion of the variance in males.

b) Age: Anaerobic power seems to increase with age to reach a maximum of 1.5-1.6 kgm/kg.sec at 20-30 years after which it decreases progressively to less than half of the maximum at approximately 70 years (Margaria et al., 1966).

c) Sex: Age and sex are factors in development of power on a 30 s bicycle test. Cumming (1973) tested 10 boys and 10 girls, aged 15 years and found the mean work rate for boys to be 443.2 ± 53.0 W and 298.4 ± 55.4 W for girls. Corresponding serum lactate levels were 11.8 ± 0.8 mM/L and 11.8 ± 2.1 mM/L. Similar differences occur at other ages. Structurally, elite male and female track and field athletes have similar muscle fibre composition and enzyme activities but males tend to have larger fibre areas than females (Costill, Daniels, Evans, Fink, Krahenbuhl and Saltin, 1976). Devries (1974) compared world athletic records of 1963 of men and women and found greatest differences in explosive power events between the sexes. Generally, women suffered by far the greatest injuries in explosive efforts compared to other activities. Supposedly, this was due to the female musculoskeletal system being unsuited to such activities.

d) Psychology of Performance: Probably the least studied area of power is the psychological one. Motivation, incentive, pain tolerance, awareness, and concentration play an undetermined role in the manifestation of power. Little research has been done on perception of exertion in the 30-100% range of maximal voluntary contraction (Knuttgen, 1975), that of many brief power tests.

e) Diet and Ergogenic Aids: An insufficient diet or the use of anabolic steroids can lower work capacity. Induced blood alkalosis has little effect on maximum performance time, total lactic acid found or lactic acid appearance rate in the blood in a supramaximal exercise lasting 27 to 153 s (Margaria, Aghemo and Sassi, 1971).

f) Training: The worth of power and general fitness development programs is well documented. Training with 220 yd interval spring runs over 6 weeks has led to increases in maximal anaerobic run times on the treadmill by 23% (36 to 66 s), increases in blood lactate concentration of 17% and 9% increase of O_2 debt (Cunningham and Faulkner, 1969).

Men aged 34-37 years have adapted to 6 weeks intense anaerobic hill running. Houston and Thomson (1977) showed a 16.7% increase in anaerobic capacity on the treadmill test (Cunningham and Faulkner, 1969) was accompanied by a 14% increase in the terminal blood lactate level. Muscle ATP increased while LDH activities, CP level, fibre types, and anaerobic power or the stair run (Margaria et al., 1966) did not change.

Training at low anaerobic power output may elicit similar aerobic and anaerobic physiological changes as with high power output. Fox, Bartels, Klinzing and Ragg (1977) studied the effects of a high power training stimulus, 19 repetitions of 30 s runs and lower power, 7 repetitions of 120 s runs for 3 days per week for 8 weeks. Net lactate significantly decreased in both groups, the greater decrease occurring in the low power group. They suggested that increases in muscle mitochondria resulted in greater decreases in lactate at a given work rate. Chronic anaerobic training changes did not necessitate a short high power stimulus.

Intensity may be a major factor in power training for specific subjects groups or tasks. Weltman, Moffatt and Stamford (1978) trained 19 college women, 3 times per week for 6 weeks using a high power test protocol on the bicycle ergometer. The protocol included all-out (fast as possible) pedalling at a load of 4.0 kg and was done twice per day. Significant improvements were found in aerobic power, 10.5%, 4 s peak anaerobic power, 13%, and 40 s anaerobic capacity, 12%. Intensity, seemingly more than duration or frequency of training sessions, elicited the change.

Thomson and Garvie (1979) showed that sprinters expend more anaerobic energy in a one minute exhausting spring than marathoners or control subjects. The athletic groups had a higher alactacid contribution that lasted longer into the one minute spring period. However, the findings of Hagberg, Nagle and Carlson (1978) indicated that trained individuals seem to increase their aerobic energy contribution more rapidly at the onset of exercise; they have slower phosphagen and glycolytic depletion following short term work at equal, absolute loads to the untrained performers.

Specific Body Structure

a) Gross Body Dimensions: According to Astrand (1970), maximum power is proportional to the square of body height approximately. However jumping height, a measure of power in the vertical jump, is independent of the size of the jumper because of the cancelling effect of the body height and body mass. A jump over a bar would be more easily performed by a tall person whose centre of gravity initially lies higher than a short person.

The relationship of potential power output to leg muscle and overall body size has been established. Davies (1971), comparing maximal power outputs of adults on jumping, stair running and maximal aerobic exercise on the bicycle ergometer, found significant correlations between power on stair climbing and vertical jump with weight and thigh muscle: stairpower with weight, r = 0.79; vertical jump with weight, r = 0.58; stairpower with thigh muscle, r = 0.74 (0.30 with weight and height factored out); vertical jump with thigh muscle, r = 0.62 (0.31 with weight and height factored out); stairpower with total muscle, r = 0.72; and vertical jump with total muscle, r = 0.55. The contribution of working muscle mass and overall body size was evident. Davies concluded that muscle mass for a given body size remained unchanged with age but muscular energy stores and utilization declined.

Davies, Barnes and Godfrey (1972) indicated that, in children 6-16 years of age, leg volume was related to explained sex and age differences in $\dot{V}O_2$max and statistically accounted for over 80% of the total variance of power output for the group. The correlation of power on the Margaria stair run with weight and leg volume was 0.89 and 0.91 for girls and 0.85 and 0.81 for boys respectively. Functional capacities of children are closely matched to leg and total body dimensions. In contrast, subjects older than 35 years showed a complete lack of association between indices of body composition and maximal aerobic power.

Tests of intermediate duration also show structure and function associations. Katch (1974) studied male college students performing heavy intensity work for 2 minutes on a bicycle ergometer. Body weight, leg volume and leg weight accounted for 41, 36 and 26% of the common variance in total work output and collectively 46%. When work became more intense, either with increasing time or load, factors such as weight determined more of the individual differences in work output than in short light exercise. Katch and Weltman (1979) found body weight associated with 6 s peak power output, $r = 0.40$, and 2 minute anaerobic capacity, $r = 0.71$. Leg volume association was less, $r = 0.29$ and $r = 0.01$ respectively. The intercorrelation of body weight and leg volume was $r = -0.46$.

b) Fibre Types: Body structure from a histochemical approach also adds information about gross body structure and athletic functioning. The categorization of muscle into fibre types according to contractile and metabolic characteristics allows cellular rationalization of some of the variance in anaerobic power output among athletes. As Saltin (1973) concluded, fast twitch fibre types usually have a larger diameter than ST fibres and thus occupy a larger portion of the muscle than indicated by percentage. The area occupied by one fibre type can be altered by training. Size of muscle fibre varies with sex and activity. Gregor, Edgerton, Perrine, Campion and Debus (1979) indicated females have larger ST fibres relative to FT than males. FT fibres in individuals involved in high power, low endurance were of a greater relative size than high endurance competitors. ST size was similar for both types of effort. When force was divided by body weight, greater force capacity was associated with FT fibres.

Higher fatiguability of human skeletal muscle occurs in repeated fast, maximum, dynamic contractions than otherwise. Thorstennson and Karlsson (1976) showed a high degree of association between leg fatiguability on 50 contractions on an isokinetic apparatus (Cybex Corp.) and % FT fibres in the quadriceps muscle ($r = 0.86$). Muscles rich in FT fibres showed higher maximal contraction velocities and higher force outputs during maximal voluntary isokinetic contractions at high speed than ST (Thorstennson, Grimby and Karlsson, 1976). FT fibres exhibit a high potential for fast turnover of Ca^{2+} and ATP for muscle contraction and high ATP production via anaerobic processes. They suggested failure in this as well as in excitation-contraction coupling at the neuromuscular junction lead to greater fatigue in FT fibres. Tesch, Sjödin, Thorstennson and Karlsson (1978) further elucidated that in 30 s of isokinetic exercise, a lactate concentration gradient existed between FT and ST that disappeared after 60 s. High glycolytic enzyme activity of LDH and M-LDH enhanced the rapid formation of the gradient.

The possibility of changing fibre types is unclear currently. Komi and Karppi (1975) stated performance capacity was influenced strongly by fibre composition which in itself was almost solely determined by the genetic factor. However, Jansson, Sjödin and Tesch (1978) suggested that specific anaerobic training or immobilization could lead to radical shifts of % FT fibres to ST and conversely aerobic could drastically increase % ST.

Selective recruitment of muscle fibres occurs according to exercise intensity. Anderson and Sjøgaard (1976) have shown the order of recruitment of fibres, with differing activation thresholds according to increasing exercise intensity, to proceed from type I to IIA to IIB. Also differential glycogen depletion of fibres occurred according to intensity. Similarly Thomson, Green and Houston (1979) showed that repeated 1 minute bouts of supramaximal exercise resulted in a greater decline in PAS straining in the FTb fibres with little loss of glycogen from ST fibres, compared to submaximal prolonged work. Submaximal exercise (60% $\dot{V}O_2$max) resulted in a 77% decline of muscle glycogen while 10 supramaximal bouts resulted in a 52% decline.

The application of knowledge of muscle composition to field athletic applications is possible but not straightforward. Komi, Rusko, Vos and Vihko (1977) investigated 89 elite athletes in various sports. They indicated that anaerobic capacity of the whole body as tested by the Margaria stair run, maximal leg force and blood lactate was related to % FT fibres. Inbar, Kaiser, Dotan, Bar-Or, Schéle and Karlsson (1979) tested fibre types, 30 s all-out power on the Wingate protocol (with peak power) and runs of various distances on male adults. Prediction of running performance by multiple regression analysis for 40 m was best using the factors of peak power and % FT (R = 0.79), for 300 m, total 30 s power and peak power (R = 0.72) and for 2000 m the 30 s fatigue index from the Wingate test, total power and % ST (R = 0.71). Campbell, Bonen, Kirby and Belcastro (1979) maintain muscle fibre composition is usually not correlated with objective measures of performance. Exceptions were possible subject to type I errors.

c) Muscle Arrangement: Muscle arrangement in antagonistic pairs reduces the theoretical limit of all single loaded muscles of the body, all contracting simultaneously, from approximately 8000 W to 4000 W, as suggested by Wilke (1960). Shephard (1972) maintained that power is more important than speed of movement in the hip and shoulder girdle where the muscle arrangement is pennate and the individual fibres are inserted angularly to the main tendon; where fibres are arranged longitudinally (fusiform), power is subordinate to speed.

Josephson (1975) summarized the importance of muscle arrangement and size on the force-velocity relationship within muscle itself. Other factors being equal, the maximum force produced by a muscle should be proportional to its cross-sectional area and hence, the number of parallel myofilaments as in pennate muscle arrangements; forces in parallel are additive. Similarly, maximum shortening velocity should be proportional to its length. Longer muscles have more contractile elements in series; the velocities in series are additive. Thus maximum work, the product of force and distance, or power, the product of force and velocity for a set of contractile elements is the same whether the elements are in series or parallel. Emphasis might be placed on any of the force, velocity or distance vectors for specific tasks or individual subjects.

d) Lever Systems: The longer the limb, the smaller the fraction of maximum force or weight that can be used to produce the greatest power output. A short lever arm such as in the olecranon-triceps lever provides more speed than power for throwing, whereas the calcaneum-gastrocnemius system lends more power (Shephard, 1972).

e) Neural Contributions and Coordination: Knuttgen (1975) suggested the limits to endurance in repeated movements were within the central nervous system, at the myoneural junction or in the inability of the muscle cell sarcolemma to propagate a second wave of excitation. Thorstensson and Karlsson (1976) tested the fatiguability of the quadriceps muscles to fast repeated isokinetic knee extensions. They suggested that failure of the excitation-contraction coupling as well as in the ATP supplying mechanisms may account for the greater susceptibility to fatigue in FT muscle fibres than in ST. Hence, a site of fatigue could be the motor neuron.

Coordination and timing during cycling can be limitations to performance. For example, Harrison (1963) studied the variation of muscle speed during various motion patterns. Holding the input velocity constant and optimizing the advance time to the pedals, in order to force exercise, increased the power output over that possible in simple harmonic motion of the pedals.

f) Series Elastic Elements: Harrison (1963) also maintained that if the series elastic component was absent in pedalling, a calculated increase in power of 18% was possible. The stiffness of the series elastic component increases with increasing load and varies between individuals. Thus subject differences, coordination and muscle compliance affect power output in bicycle ergometry.

Specific Body Function

a) The Force-Velocity Relationship: Light loads can be moved more quickly than heavy loads. Maximal force is developed during an isometric contraction when the velocity is zero. Hill (1922) showed in isolated muscle preparations that stimulation evoked development of maximal force but that viscous resistance of the muscle substance used up some of the force during the shortening of the muscle. Fenn and Marsh (1935) investigated isotonic contractions in isolated muscle preparations and showed the exponential relationship of force and velocity. The curve was concave towards the origin. Hill (1938) showed the shape of the force-velocity curve was determined by the way energy was released during shortening. He related force and velocity as a hyperbola:

$$(P + a)(V + b) = \text{constant} = (P_o + a)b$$

where P = force of contraction

V = velocity of shortening

a, b are constants

P_o = force possible in an isometric contraction at zero speed

Thermal as well as mechanical properties were related to one expression.

Wilke (1950) has demonstrated the hyperbolic force-velocity relationship shown previously on frog muscle in vitro applies in human muscle movements in vivo. He studied isometric and isotonic elbow flexions and found experimental results did not fit the characteristic Hill equation except at tensions greater than 0.3 P_o. He then corrected for inertia of the forearm and apparatus and found agreement.

Wilke (1960) evaluated maximum pedalling speeds. Maximum pedalling rate under no-load conditions, was about 180 rpm, the optimum for greatest steady-state pedalling being about 60 rpm;

the speed used in cycling competitions ranged from 60 to 120 rpm where efficiency is compromised for maximum performance.

Speed may not have a close association with impulse power. Gray, Start and Walsh (1962) investigated the association of leg power as measured by the vertical jump and leg speed as measured on a 10 s ride on a bicycle ergometer at a resistance setting of 2.5 kg. The low correlation of 0.47 between speed and power so-defined, indicated high specificity in the two fitness components. The force setting was fixed and the force-velocity relationship in determining speed was not accounted for. Start, Gray, Glencross and Walsh (1966) further investigated 19 measures of the lower limbs: seven of isometric strength, four of power (various jump tests), seven anthropometric measures and the bicycle speed test Gray et al., 1962). Power was linked with speed more than strength. They postulated that strength is an estimate of maximum energy available at one instant and is independent of time. Speed would be independent of mass but only approximated in measurement due to an ever present but minimal limb mass.

The intercepts of the hyperbolic force-velocity curve may represent on the one axis the maximal velocity of muscle shortening, Vmax, and maximal isometric tension developed, P_o. Katz (1972) interpreted the biochemical significance of Vmax as the maximal rate of ATP energy turnover per unit length of muscle as influenced by myosin ATPase. P_o represented the number of force generating sites per unit cross-section, influenced by the amount of Ca^{2+} available to the contractile proteins. The shape of the curve reflected the rate of activation of force generating sites per unit of muscle cross-section. The derivative dP/dt reflected an alteration in the rate of delivery of Ca^{2+} to the contractile proteins. He described the model of force-velocity relationships as an empirical index rather than a direct determination of a specific property of contraction.

Whitt and Wilson (1974) indicated that high pedalling speeds are possible for competitive cyclists in brief events. R. Temple pedalled at an estimated power output of 1007 W and a crankspeed of 190 rpm in a 30 s ½ mile event.

A "most efficient" pedalling rate has been suggested for each power output. Seabury, Adams and Ramey (1977) suggested a balance between two forces: the reduction of load on each fibre per contraction and a reduction of the total number of contracting fibres. The "most efficient" pedalling rate increased with power output from 42 rpm at 40.8 W to 62 rpm at 362.8 W. In effective recruitment of fibres or increased effect of internal viscous friction in muscle tissue were reasons suggested for decreased efficiency at speeds higher and lower than "most efficient".

Sjøgaard (1970) obtained hyperbolic force-velocity curves for subjects pedalling at frequencies from 40 to 160 rpm. Speed and force were determined on four to five revolution outputs as well as at 70% and 100% of $\dot{V}O_2$max. The curves had the same slope and shape as the Hill curve but not the same fit. He suggested that in bicycle exercise "negative work is done at each step before the positive work" and with work stored as elastic energy and released in the positive phase of cycling. Gravity factors and multiple joint action were also possible contributors. He demonstrated that peak force per pedal thrust (and as a % MVC) decreased with increasingly pedal frequency. He demonstrated that FT fibres were recruited for short heavy efforts with their shorter contraction times. Ratings of perceived exertion were minimal at approximately 80 rpm for a constant power output despite the fact that $\dot{V}O_2$, heart rate and ventilation are low at 40-60 rpm. He reasoned a reduced strain on the mechanoreceptors as the reason for preferring high pedal frequencies. Gregor, Edgerton, Perrine, Campion and Debus (1979) maintained that low isokinetic speeds of knee extension showed more influence of fibre type than fast or zero speed conditions. Optimal speed and torque are likely.

b) Type of Contraction: Knuttgen (1976) related the relationship of maximal force of human elbow flexor muscles to elbow position for three types of contraction. Eccentric or "forced" contraction gave the greatest force, isometric the intermediate force and concentric the least. All contractions were one repetition of maximum voluntary force.

c) Position or Angle: Knuttgen found the above relationships of the three types of contractions to be somewhat hyperbolic with each having a characteristic maximum force point at a particular joint angle between 90 and 120 degrees. Thorstennson, Grimby and Karlsson (1976) studied dynamic torque in isokinetic knee extensions throughout 90° of motion. Peak torque was reached at knee angles in the range of 55 to 60 degrees, with a displacement toward smaller knee angles at higher angular velocities.

d) Length-Position of Muscle: A. V. Hill (1938) described the velocity of a muscle as being proportional to the force acting, P and the isometric force that the muscle can develop at its optimal length, Po. The hyberbolic relationship was valid only for the length, Lo, at which Po was optimal; however it can be modified for different muscle lengths. At a cellular level, the maximum tension developed between a thick filament in a muscle and its surrounding thin filaments should be proportional to the number of potentially active cross-bridges hence to the amount of filament overlap as exemplified in the tension-length curve (Josephson, 1975).

e) Mode of Movement: Wilke (1960) found that simultaneous hand cranking and cycling yielded approximately 50% more power than cycling alone, but could only be done for a short duration. Harrison (1970) compared various combinations of rowing and bicycle ergometry for exercise durations from 6 s to 5 min. Forced rowing movement with feet moving and seat fixed allowed maximum power production: 1492 W for 6 s; 746 W for 1 min and 560 W for 2 min. He suggested that the mode of working should allow use of as large a muscle mass as possible; that the motion should be forced to minimize kinetic energy losses, and that the motion should minimize inertial effects.

Davies (1972) investigated a range of ages of adults for maximal power in different tests. He found standing jump power outputs four times larger than those on a Margaria stair run and fifteen times larger than the power output at maximum aerobic work on a bicycle ergometer. Maximum power output was independent of age, sex, size, stature and to a lesser extent, body composition in his study.

f) Warm-up for Exercise: Watt and Hodgson (1975) cited increased core and muscle temperature, respiratory and circulatory adjustment, joint mobility and avoidance of ischaemic changes in myocardium as factors enhanced by warm-up. They measured $\dot{V}O_2$ during and after 1 minute runs to exhaustion on the treadmill and found $\dot{V}O_2$ during the run preceded by warm-up 7.6% greater than without warm-up. Oxygen debt was not however correspondingly lower. Bar-Or (1977) suggested a 10 min intermittent warm-up (30 s exercise, 30 s rest) with mean heart rate reaching 160 bpm in children and 150 bpm in young adults. An all-out trial of 5-10 s allowed familiarization. Inbar and Bar-Or (1975) found that 7 to 9 year old boys benefited from warm-up before a 30 s supramaximal trial on a bicycle ergometer. Total revolutions, total power output and peak HR were higher following intermittent resting and running at 60% $\dot{V}O_2$max for 15 min preceding the criterion test.

g) Recovery from Exercise: Because lactate buildup in muscle has been postulated to be a limiting factor for physical performance of short duration (Wenger and Reed, 1976), its time course after exercise indicates when subsequent efforts can be performed without decrement. Sahlin, Harris, Nylind and Hultman (1976) investigated lactate, pyruvate and pH levels in blood and muscle during recovery from exhaustive exercise. The half-time of blood lactate decrease was 9.5 min. The ratios lactate/pyruvate and NADH/NAD were increased after exercise and had not returned to basal value after 20 min, although they were substantially restored; muscle pH had returned to basal level.

Physical exercise resulted in a marked decrease in muscle phosphocreatine (PC) but not much in ATP. The decrease in PC was correlated with an increase in muscle lactate concentration. The restoration of PC, like pH, after dynamic exercise took approximately 20 min with a half-time of 170 s for the slow component. The fast component kinetics (half-time of 22 s) resembled the 25 s fast component of oxygen debt (Harris, Edwards, Hultman, Nordesjo, Nylind and Sahlin, 1976). Similarly, the total adenine nucleotide content of muscle (TAN = ATP + ADP + AMP) was restored to basal level after maximal dynamic exercise within 30 min (Sahlin, Palmskog and Hultman, 1978).

Weltman, Stamford, Moffatt and Katch (1977) found on successive supramaximal tests on the bicycle ergometer than the rate of normalization of lactate levels in recovery was enhanced by 20 minutes recovery duration (as opposed to 10 min) and an active mode over a passive mode. Oxygen inhalation did not enhance recovery. They suggested an optimal intensity for recovery exercise as just below anaerobic threshold. Factors other than lactate removal were critical for subsequent efforts because blood lactate levels after 20 min of recovery were not highly correlated with subsequent work ($r = -0.19$).

Lactate removal from the blood seems to depend on the metabolically active muscle mass. McGrail, Bonen and Belcastro (1978) found association between $\dot{V}O_2$ and lactate removal rates of various active and passive recoveries (utilizing arms and legs for active recovery).

Stamford, Moffatt, Weltman, Maldonado and Curtis (1978) subsequently studied lactate disappearance in 24 min recovery periods after supramaximal 1 min cycling. They suggested low intensity recovery exercise at approximately 30-45% $\dot{V}O_2$max (~50 W) compared to rest or higher intensity exercise would keep lactates low and enhance muscular and splanchnic removal rates.

Measurement and Expression

a) Expression: Anaerobic power has been discussed above in terms of supramaximal efforts of durations so short that aerobic involvement is highly limited and in terms of sustained aerobic work where additional intensity and duration of effort is attained by anaerobic mechanisms. Indicators of anaerobic power and capacity for the latter type of effort include rate of formation and total accumulation of lactic acid in blood and muscle (Agnevik, Karlsson, Diamant and Saltin, 1969), acid-base equilibrium of the blood (Sherrer, 1969), maximum oxygen debt (Margaria Edwards and Dill, 1933), excess CO_2 (Volkov, Shirkovets and Borkevich, 1975) phosphoralase and PFK activities, pH, ATP-CP glucose, glucose-6-phosphate, and glycogen changes (Gollnick and Hermansen, 1973).

Apart from physiochemical methods, performance-oriented or mechanical tests have been used to measure anaerobic work, power and duration of effort. The vertical jump has been used although it may not be distinctly a measure of human power. Adamson and Whitney (1971) argued that the vertical jump is an impulse action, the product of force and time, equal to momentum (mass x velocity) imparted to an object. Power production was completed before substantial dissipation of force. Instantaneous actions have been more often classified as impulse rather than power. However, Davies and Rennie (1968) reported mean peak power outputs of 3894 W (52 W/kg) in vertical jumps on a force platform exemplifying impulse power.

The power test most used, apart from the vertical jump, has been the Margaria stair run. Such a test also involves lifting the centre of gravity of the body in a series of bursts of power. It also involves successive limb movements. The test time is approximately 0.40-0.50 s. Average power output is 15.9 W/kg for young fit subjects decreasing to 7.9 W/kg at 70 years. A value of 27.8 W/kg was reported for an Olympic sprinter (Margaria, Aghemo and Rovelli, 1966). DiPrampero, Limas and Sussi (1970) reported comparable values on athletes at the 1968 Mexican Olympic Games. The higher power per kg body weight found in athletes compared to the normal population seemed mainly due to their lower body fat levels. Anaerobic power was not affected by altitude or racial differences.

Costill, Miller, Myers, Kehoe and Hoffman (1968) investigated the relationships among various impulse power tests along with some anthropometric measures in the 76 male football players. Margaria's stair test correlated with squat life ($r = 0.751$). Weight correlated $r = 0.783$ and 0.848 with squat lift and the Margaria test respectively. Other impulse tests and body parameters showed significant but mediocre correlations. Body weight appeared to account for the relationship between squat lift and anaerobic power.

A variety of anaerobic test protocols for the treadmill have been used. Cunningham and Faulkner (1969) used a short exhaustive at 11-13 km/h on a 20% grade with run times varying from 36 to 66 s. A six week training program of interval sprints and distance runs resulted in a 23% increase in running, 9% increase in oxygen debt and 17% increase in blood lactate concentration, the three factors used as indicators. Watt and Hodgson (1975) employed a 12.8 km/h run at 10 to 20% grade which produced exhaustion in subjects in 60 s. $\dot{V}O_2$ during the run was higher with warm-up than without although recovery $\dot{V}O_2$ and total $\dot{V}O_2$ (run + recovery), expressed in gross or net values, were not greater. Cerretelli, Ambrosoli and Fumagalli (1975) employed a 20-30 s exhausting run at 18 km/h and grade from 10 to 15%, set to develop power at 2.5 times the power at $\dot{V}O_2$max. They found higher lactate levels (by 16.9%) during 3 min at $\dot{V}O_2$max immediately following the short run than in 3 min of rest, thus they suggested anaerobic recovery with partial phosphagen resynthesis at the expense of anaerobic glycolysis. Roberts and Morton (1978) utilized 25-40 s exhausting runs at 14.5-16.1 km/h, 20% grade to demonstrate high reproducibility of alactic oxygen debt. They suggested that the inability of the subjects to adequately reproduce such an effort was the major factor preventing reliable measurement of oxygen debt. Trials two days apart had mean power outputs of 650.4 W and 589.6 W and respective durations of 32.5 s and 29.4 s.

b) Bicycle Ergometer Tests and Loading: The bicycle ergometer also has been used as a test mode for anaerobic power. A survey of such tests is given in Table I with the resistance and cadence settings characterizing the force-velocity relationship of each

TABLE I

SURVEY OF ANAEROBIC POWER TESTS FOR THE BICYCLE ERGOMETER

Reference	Frictional Resistance or Force	Cadence or Velocity (rpm)	Duration (s)	Power Output (W)	Test - Retest r
Wilke (1960)	-	-	120	403	
Harrison (1970)	-	allout	6 s	-	
			18 s	-	
			30 s	-	
			60 s	-	
			120 s	-	
			300 s	-	
Karlsson & Saltin (1971)	-	-	60	458	
Cumming (1973)	4.5 kp	allout	30	443 ± 53	
	4.0 kp	allout	30	298 ± 55	
Katch (1973b)	5.5 kp	85 ± 7.5	60	473	
Katch (1974)	~ 5.6 kp	97	120	-	0.92
Ayalon et al. (1974)	explosive leg 2.9 kg	allout	1 RM	-	0.92
	explosive leg 40 g/kg	allout	1 RM	461 ± 83	0.93
	Margaria step -	allout	< 1	1007 ± 109	0.85
	30 s leg 40 g/kg	allout	30	590 ± 39	0.91
	30 s arm 20 g/kg	allout	30	303 ± 30	0.93
Inbar et al. (1975)	40 g/kg	allout	30	-	
Inbar & Bar-Or (1975)	35 g/kg	allout	30	298 ± 55	

TABLE I (Continued)

Reference	Frictional Resistance or Force	Cadence or Velocity (rpm)	Duration (s)	Power Output (W)	Test - Retest r
Katch et al. (1976)	5.6 kp	allout	30	539	
			(60)		
			(90)		
			(120)		
Katch et al. (1977)	5.5 kp	60	120	299	
		80	120	327	
		100	120	337	
		allout	120	338	
	4.0	allout	40	473 ± 35	
	5.0	allout	40	515 ± 46	
	6.0	allout	40	530 ± 51	
Bar-Or et al. (1977)		allout	30 s		0.95 - 0.97
Heyters + Poortmans (1977)	3.5 kp	126	51.3 ± 11.2	433	0.80 - 0.85
Pirnay & Crielaard (1978)	4-7 kg	allout	<10	710 ± 58	
Stamford et al. (1978)	2.5 kg	allout	60	248 ± 19	
Weltman et al. (1978)	4.0 kp	allout	40 s	355 ± 41	
			peak 4 s	511 ± 56	
Campbell et al. (1979)	1.5 (F at $\dot{V}O_2$max)	allout	20	-	
	0.5 (F at $\dot{V}O_2$max)	allout	20	-	
Katch & Weltman (1979)	~5.6 kp	allout	120	358 ± 10	
			peak 6 s	678 ± 63	
Mayers & Gutin (1979)	1.5 kg	allout	30	159 ± 21	

particular test, duration of test and resulting power outputs. Most tests had fixed resistance settings that are the same for all subjects or are relative to body weight, as an anthropometric parameter, or to $\dot{V}O_2$max, as a physiological function of the individual subject. Cadences are maximal all-out or fixed submaximal cadences. Durations range for peak 4 s values to 120 s total time, indicative of the anaerobic time course for maximal exercise.

The resistance setting used by investigators at the Wingate Institute is based on the subject's body weight. Using the 30 s time frame proposed by Cumming (1973), they investigated power to force curves of five untrained young adult males (19-21 years, mean weight 71.93 kg) and concluded that a relative setting of 40 g/kg elicited maximal power output (Ayalon, Inbar and Bar-Or, 1974). Thus one trial with a resistance setting relative to weight approximated the maximal power output from an individual subject's power to force curve. Inbar and Bar-Or (1975) used a setting of 35 g/kg (mean value = 0.95 kp) on 7 to 9 year old boys to demonstrate the effects of warm-up before the 30 s test.

Katch, Weltman and Traeger (1976) studied the effects of two different cycling cadences on work output of short (120 s) duration. The frictional setting was constant at 34.0 kp/rev (≐ 5.6 kp). The paced-ride cadence started at 9.7 rev/6 s corresponding to 539 W and 80-90% of the all-out cadence. More revolutions and greater work output was found under the all-out condition for 0-30 s and 0-60 s but more work was accomplished under the paced condition from 30 s to 60 s. All other possible time intervals from 0 to 120 s for the 2 cadence conditions were not significantly different from each other. (The authors used a 6 s time increment for measurements.) The all-out cadence was required for maximal power on a 30 s or 60 s test. Katch, Weltman, Martin and Gray (1977) investigated optimal test characteristics for anaerobic power. They stated a test duration of approximately 40 s at a resistance of 5.0 to 6.0 kp with an all-out cadence was necessary for maximal power. At a constant load of 5.5 kp, cadences of 60, 80, 100 and all-out rank-ordered themselves up to 24-30 s as to work achieved. The 40 s time frame was chosen because the aerobic contribution to work is appreciable after that point and the total cumulative work up to 40 s correlated highly ($r = 0.95$) with total cumulative work of 120 s duration. Correlations of body weight and leg dimensions with total cumulative work indicated a moderate but definite association of high work output with high body weight, legs and total body muscle.

Heyters and Poortmans (1977) also evaluated a bicycle ergometer test of anaerobic power. The supramaximal test intensity was 433 W and the cadence 126 rpm. Duration of effort was the index of capacity and was 51.3 ± 11.2 s for the 28 twenty-one year old physical education students. The correlation ($p < .05$) of the test with the 400 m run was $r = 0.397$ and with peak lactate concentration $r = 0.63$ to 0.78.

A short test was developed by Pirnay and Criellard (1970). Their 32 physical education students pedalled all-out at force settings between 4.0 and 7.2 kg at their maximum power. They attained maximum in 2 to 3 s and maintained it for about 4 s. The cadence was 130-150 rpm. The power to force relationship and cadences shown on successive trials by all subjects demonstrated that the optimal intermediate force and cadence, rather than maximal or minimal, enabled maximal power output for each subject. Performance ranged from 576 to 859 W (710.1 ± 58.4 W) in absolute values and 7.9 to 12.4 W/kg (10.1 ± 1.2 W/kg) on a relative basis. Two sprinters performed at 1018 W, 14.2 W/kg and 1059 W, 16.0 W/kg. The coefficient of variation ranged from 1.6 to 3.4% with a mean value of 2.84 for retest performances.

Katch and Weltman (1979) employed a 120 s all-out cycling protocol. Anaerobic power was designated the peak power during a 6 s interval usually the first 6 s interval in 120 s. Anaerobic capacity was the total work output during 120 s. They suggested the power score was indicative of phosphagen splitting and the capacity score indicative of glycolytic production of ATP. Moderate correlations of their power scores with weight (r = 0.40) compared to those of the Margaria test (r ≥ 0.90) suggested to them that their power index was indicative of the ATP-CP system and not very dependant on weight.

c) Reliability: The test-retest reproducibility of anaerobic power tests is high, as exemplified in Table I.

d) Validity: The 30 s power test may be limiting in predicting performance well for adolescents. Cumming (1973) found the test proved to be a significant predictor for the 100 yard run in boys (r = 0.55) and for the 440 and 880 yard runs for girls (r = 0.41 and r = 0.43 respectively). It was inadequately to highly correlated with performance in Margaria's stair run. Age and maturation may confound prediction of athletic performance in children.

Bar-Or, Dotan and Inbar (1977) validated the 30 s bicycle test for anaerobic capacity. Its correlation with 300 m run time was r = -0.85, with maximal oxygen debt r = 0.86 and with 25 m swim time r = 0.87 to 0.90. Inbar, Kaiser, Dotan, Bar-Or, Schéle and Karlsson (1979) used the 30 s anaerobic bicycle ergometer test and fibre type distribution to predict performance in 40 m, 300 m and 2000 m runs. Peak power (PP) and % fibre type were predictors for 40 m (R = 0.89), PP and total 30 s power (TP) for 300 m (R = .92) and fatigue index over 30 s (F), TP and % ST fibres for 2000 m (R = 0.71) for 29 middle and long distance runners, PE students and sedentary men.

Physiology and Energetics

a) Phosphagens: Previous to 1930, the Hill-Meyerhof Theory outlined the formation of lactic acid from glycogen as the fundamental reaction of muscular contraction. However, the immediate source of energy for muscle shortening has been recognized for some time as ATP and CP. The confirmation of the relationship of ATP and CP has been only recently established in man. Hultman, Bergström, McLennan and Anderson (1967) measured phosphagen levels on human subjects exercising on a bicycle ergometer and established the role of phosphagens as the immediate energy source for contraction. ATP is not stored in muscle, its concentration being 5 to 7 mM, it would be depleted in less than one second during contraction unless it was resynthesized at a rate equal to utilization (Newsholme, 1978). Even after complete exhaustion, the concentration of ATP is 60-70% of that in the resting cell though CP can be nearly fully depleted (Gollnick and Hermansen, 1973). CP is three times as plentiful as ATP and is in series with ATP in providing the energy currency ATP from phosphate pools (Margaria, 1976).

b) Glycolysis: Glycolysis results in the production of energy, lactate and other acid products associated with fatigue. As Margaria, Cerretelli, DiPrampero, Massari and Torrelli (1963) indicated, the rate of increase of lactic acid is linearly related to the intensity of supramaximal exercise. Karlsson and Saltin (1970) also indicated increasing intensity of work stimulates glycolytic activity. Noradrenaline level in blood has been found to be related to relative workload and this may be responsible for activation of phosphorylase enzyme during muscle contraction. PFK was inactivated by high ATP concentrations and stimulated by an anaerobic cellular state. Saltin and Karlsson (1971) found that at an intensity of 150% $\dot{V}O_2$max, the utilization rate of glycogen can be 10 mM glucose units x kg^{-1} wet muscle x min^{-1}. At very heavy loads, more than a tenth of the muscles normal glycogen store was used per minute but depletion was not as great as in longer bouts at moderate intensities. They concluded accumulation of anaerobic metabolites may have been a more limiting factor at intensities of exercise exceeding 90% $\dot{V}O_2$max but glycogen depletion seemed of negligible importance. Karlsson (1971) indicated skeletal muscle lactate can rise to 20-30 mM/kg. In this instance lactate in blood and other fluids rises as a consequence of lactate diffusion from muscle fibres. Muscle lactate concentrations remained high through

5 successive supramaximal efforts of 1 min duration, parallel to the subjects' perception of fatigue. But levels of glycogen, G-6-P, ATP, CP, ADP blood lactate and oxygen deficit increased through the trials (Karlsson and Saltin, 1971).

Subjects with muscles rich in FT fibres have been found to have a higher anaerobic capacity on an exhausting bicycle test. This was indicated by Tesch (1978) who found a significant relationship between lactate concentration and performance time at an intensity of 120% $\dot{V}O_2$max ($r = 0.76$). Also he found a relationship between % FT fibres and lactate formed ($r = 0.85$).

Wenger and Reed (1976) summarized factors responsible for fatigue during anaerobic work. Increased lactate and consequent acidity could reduce PFK activity, thus reducing permeability of the muscle membrane to sodium ions thus altering muscle action potential and increase competition of H^+ with Ca^{2+} for binding sites on actomyosin. Also depletion of glycogen, delay in phosphorylase b activation, reduced hydrogen ion acceptor NAD^+ in the cytoplasm and decreased inorganic phosphate in muscle fibres lead to general decreased glycolytic energy production, decreased available phosphagens in the muscle and consequent muscle fatigue. Increased metabolites and decreased contraction ability limit brief, high-intensity activity. Other factors could be uneven lactate diffusion to body compartments and fluids with varying total body water, oxygen deficiency, and varying active metabolism of lactate to glycogen, water + CO_2 or pyruvic acid (Astrand, 1976); base deficit (Sahlin, Alvestrand, Brandt and Hultman, 1978); or reduction of central buffering capacity with peripheral or central mechanisms (Sharratt and Jones, 1978). As early as 1969, Denolin, Messin, Degre and Vandermoten, summarized the problems of expression of lactate: in plasma or total blood, arterial, venous or muscle sampling, moment of sampling and type of effort characterized.

c) O_2 Deficit and Debt: The aerobic energy mechanism does not adapt to exercise immediately. The amount by which the O_2 uptake lags is called the oxygen deficit. Oxygen debt is equal to the amount of oxygen taken up in excess of baseline value during the recovery period. The delay in return of $\dot{V}O_2$ to resting values after exercise is due to several factors (Knuttgen, 1969).

1) O_2 stores are reduced and part of the extra $\dot{V}O_2$ used to
    (a) regenerate myoglobin stores,
    (b) regenerate dissolved oxygen in tissue fluids,
    (c) regenerate venous oxyhemoglobin;
2) increased body temperature;
3) increased adrenaline and catecholamines;
4) increased pulmonary and heart functions;
5) and most important, regeneration of ATP-CP stores.

These factors may account for 3-4 L of extra oxygen taken up after exercises that do not take part in the elimination of accumulated lactate. This quickly repaid fast-component is called the alactacid component. The remaining O_2 debt may be utilized to remove lactate produced during the work period; that is the lactacid O_2 debt. It would appear that increased debt (over deficit) would be due to a nonsteady state increase in lactacid component due to elevated anaerobic involvement.

Margaria et al. (1933) distinguished oxygen debt contracted for repayment of phosphagens as alactic and for repayment of glycolytis as lactic. They found no lactic acid detectable at low and moderate levels of work in spite of oxygen debt formation: lactic acid appeared in the blood only after strenuous exercise, linearly increasing with increasing oxygen debt.

A problem with O_2 debt measurements has been agreement on and determination of baseline $\dot{V}O_2$. Stainsby and Barclay (1969) outlined basal metabolic rate, resting $\dot{V}O_2$ and $\dot{V}O_2$ at light work as possibilities. Debt estimates obtained from a 12 minute $\dot{V}O_2$ collection period were 80-85% of the estimated debts from a one hour collection period, correlating $r = 0.90$ (Cunningham and Faulkner, 1969). The ozygen deficit may be a fairly constant amount. Karlsson and Saltin (1970) investigated the regression of muscle lactate concentration on oxygen deficit ($r = 0.88$) for various intensities of maximal work. The theoretical work value of oxygen deficit without lactate production was approximately 1.3 L. Some investigators maintain a relationship exists between O_2 debt and phosphagen breakdown. Bergstrom, Harris, Hultman and Nordesjo (1971), in studying dynamic work, stated the alactic oxygen debt is important due to the decrease in ATP-CP in working muscles.

The formation lactacid O_2 debt is probably switched on by the increase of phosphate potential in the tissues, caused by the rapid fall of ATP after exhaustion of CP stores (Cerretelli and Ambrosili, 1971). Alactacid stores averaged 100 cal/kg body weight. Maximal phosphagen splitting occurred at exhaustion, incurred by exhaustive exercise at 150-200% of $\dot{V}O_2$max in 60 to 90 s. The limiting factor for glycolysis did not seem to be glycogen stores but maximal lactic acid concentration sustained (25-30 mM/kg muscle).

Katch and Henry (1972) indicated O_2 debt may not be a valid estimate of anaerobic energy stores. They found little correlation existed between sprinting performance and maximum O_2 debt estimates. In keeping with this, Graham and Andrew (1973) found the range of O_2 debts for athletes and non-athletes to be 43 to 229 mls/kg. Interindividual variability was limited even with training whereas intraindividual variability of O_2 debt, even when compared to $\dot{V}O_2$max, was great. In explanation of this Roberts and Morton (1978) claimed the inability of subjects to adequately reproduce an exhausting supramaximal effort was the major factor preventing reliable measurement of total oxygen debt. They developed a method of measuring alactic oxygen debt that was valid and reliable ($r = 0.89$) and found that total oxygen debt was not as reproducible ($r = 0.34$). The 30 s Wingate test is predominantly anaerobic in nature. Inbar, Dotan and Bar-Or (1975) found that the 30 s test elicited an oxygen debt of 112% that of an all-out aerobic capacity test on a bicycle ergometer. They concluded that the aerobic component of a supramaximal 30 s test contributed only 13% to the overall energy demand.

Lactacid O_2 debt would appear to correspond to the anaerobic involvement beyond that required for oxygen deficit. Whether lactate contribution is measured as a noninvasive respiratory measure such as O_2 debt or as a biochemical phenomenon of muscle or blood, it appears to indicate anaerobic power and capacity components to sustaining heavy exercise.

d) Energetics and Efficiency: Karlsson (1971) suggested a total maximal energy output of approximately 30 Kcal by anaerobic processes. Margaria (1976) summarized the capacity and power of the exergonic processes taking place in maximal exercise, expressed as oxidative energy required. Respectively for the alactacid, lactacid and oxidative mechanisms, power was 48, 25 and 13 Kcal. $kg^{-1}.h^{-1}$; capacity was 100-200, 250, and infinite $cal.kg^{-1}$; maximum capacity was 20-40, 52 and undetermined $ml.kg^{-1}$; minimum time for full contraction was 8, 40 and undetermined s; and half reaction times were 0.5, 15 and undetermined min.

The efficiency for work has been expressed in a variety of ways. Margaria (1976) estimated the efficiency of the processes of energy transformation. The overall mechanical efficiency of aerobic muscular exercise was 0.25; the efficiency of the oxidative synthesis of phosphagen was 0.635; the production of mechanical work from phosphagen cleavage was 0.40; the efficiency of the synthesis of phosphagen from glycolysis was 0.76; and the overall mechanical efficiency of muscular exercise performed anaerobically at the expense of glycolysis 0.215, not much lower than in aerobic exercise. He calculated the energy equivalent of phosphagen cleavage and lactic acid formation: cal per mole phosphagen/cal per mole lactic acid = 0.8. Lactic acid was apparently utilized and formed when the unsplit phosphagen level dropped to about half the resting value.

Gladden and Welch (1978) looked at the efficiency of work for intensities of 30% to 100% $\dot{V}O_2$max. They found that both exercise $\dot{V}O_2$ and lactate were linearly related to P_{IO_2} in submaximal and short maximal aerobic exercise tests. The sum of the caloric equivalents of the exercise $\dot{V}O_2$ + fast recovery $\dot{V}O_2$ + O_2 equivalent for lactate was the same at all inspired O_2 pressures, indicating that efficiency does not change with increasing anaerobiosis. Increasing work intensity showed decreasing efficiency, regardless of energy source, aerobic or anaerobic. The delta efficiency of anaerobic work was 12% and overall work efficiency at the same work rates was 18%. The efficiency of heavy work was lower than the efficiency of light work, not due to energy sources, but possibly due to decreases in muscle efficiency and the metabolic overhead of stabilizing muscles, work of the heart and work of the respiratory muscles.

The Test Duration and Anaerobic Time Course

Exercise can be performed at high intensity or power for a brief duration of mainly anaerobic energy. Power output has varied from approximately 37 W for prolonged periods of cycling to 1119 W for a brief all-out 5 s bout (Whitt and Wilson, 1974).

The time course of phosphagen and glycolytic energy contributions to supramaximal work has been investigated. Margaria, Cerretelli, DiPrampero, Massari and Torelli (1963) studied the contraction of maximal alactacid and lactacid oxygen debt. They calculated the maximal increase of lactate in the blood during strenuous exercise to be phosphagen-splitting alone in exercise. He stated stores may last only 4 to 5 s. Slightly higher phosphagen pools found in trained subjects and the start of glycolysis before ATP-CP depletion were possible factors in modifying the time course of phosphagen breakdown. Lactate was formed even in 5 to 10 s work periods. Essen and Hagmark (1975) found lactate concentration can increase from 1.8 to 2.8 mM/kg wet weight after 10 s of maximal bicycle exercise in both fast and slow twitch fibres.

Energy required for high power arises from anaerobic fuel supplies. McGilvery (1975) listed maximum power in human muscle at the molecular level according to fuels utilized. The estimated maximum fluxes of energy-rich phosphates, expressed as mM$\sim$P/kg.s, were:

ATP,CP to ADP,Cr	1.6-3.0
Glycogen to lactate	1.0
Glycogen to CO_2,H_2O	0.5
FFA to CO_2,H_2O	0.24

The high power available from anaerobic sources is contrasted with high energy and low rate of release from oxidative sources.

The 30 to 40 s time frame seems characteristic of anaerobic power tests on the bicycle ergometer. For example, Cumming (1973) used a 30 s power test at absolute resistance settings of 4.0 and 4.5 kp, all-out cadence to test boys and girls. The 30 s time frame for power tests has subsequently been used extensively by the Wingate Institute (Ayalon et al., 1974; Inbar et al., 1975; Bar-Or et al., 1977, 1979).

In an anaerobic brief effort, aerobic involvement is small.

capacity. Subjects ran on a treadmill at 215 m/min and 20% grade till exhaustion when run time and venous lactate concentration were assessed. Net anaerobic power, work and capacity measurements are few.

The time courses of anaerobic track and field performances are parallel to laboratory measurements. Burke (1979) studied college men on batteries of laboratory tests and 10 yd (9.14 m) to 12 min runs by factor analysis. The 300 yd (274.3 m) run loaded similarly on aerobic and anaerobic factors at a mean time of 45.2 ± 3.3 s. Anaerobic supramaximal work seems best tested in 1/2 to 3/4 of a minute in the laboratory or track competition.

Climate

Power outputs on short tests seem to be stable in different climates. Christensen and Nielsen in 1936, indicated strength and speed are not affected by moderate hypoxia of P_B = 390 mm Hg on a Hill's wheel apparatus. Neuromuscular functioning of brief power bursts may not be limited at altitude (Astrand, 1970). Bar-Or, Dotan and Inbar (1977) indicated that power scores on 30 s all-out trials on a bicycle ergometer using combinations of humid and warm environments were not significantly different than in neutral climates. Lower oxygen pressure, humidity stress and thermal stress appear not to mitigate power output of brief duration.

Factors Interacting, Emphasized and Unexplained

Power output is rarely limited by a few factors, some of which are listed above. One example of an additional factor is seen in the study of Gregor, Edgerton, Perrine, Campion and Debus (1979) who emphasized the importance of controlling joint position, muscle length and moment arms simultaneously when describing torque-velocity relationships in isokinetic knee extensions. Segregating factors such as force and velocity of a movement may be an unfruitful approach to understanding human power. In addition other factors, such as heredity and muscle fibre type, may be more appropriately conceptualized together also.

The literature on athletic power may seem to revolve around certain factors such as heredity, training, fibre composition, force or speed. However, ultimate performance at the laboratory or playing field will be the result of the sum of all optimized factors. A test subject or athlete with a general disposition for power and a favourable body structure in a given physiological and physical environment and time frame, can function in an athletic activity or test situation, in such a way as to express his or her maximal or optimal power. Perhaps the ultimate testing of such power will control or measure the various known factors in order to minimize residual errors in predicting performance and account for variation in power among people.

METHODS

To establish the maximum power outputs and frictional resistance settings necessary to elicit MPO, a group of active to highly trained subjects were studied. Each subject was tested for true MPO and FMPO in a series of trials which included absolute settings at 5.0 and 6.0 kp at the beginning of the series, a randomly inserted trial at the Wingate setting, a retest of FMPO and a series of anthropometric tests. The derived predictive equations were used in single-trial testing of members of the Canadian Olympic Hockey Team (1980).

Subjects

Twelve healthy, active-to-highly trained university-level subjects (designated experimental group, EG), heterogeneous with respect to type of physical activity involvement, were selected as subjects. Included in the group were university athletes: 5 hockey players (1 of which was a goalie), 1 cross-country runner, 1 soccer player, 1 gymnast as well as 4 physical education students. They ranged in age from 21 to 33 years ($\bar{x} = 23.7 \pm 3.2$ years), in weight from 59.0 to 90.5 kg ($\bar{x} = 74.5 \pm 8.1$ kg), in total body fat from 3.2 to 11.8% ($\bar{x} = 8.1 \pm 2.6\%$). (For physical and functional characteristics, see Appendix A-I, A-II, A-III and A-IV). To obtain scores of high power in one homogeneous athletic group, twenty-three members of the Canadian Olympic Hockey Team were also tested four months prior to the 1980 Winter Olympic Games (designated Olympic group OG. (For physical and functional characteristics see Appendix A-V).

Apparatus

For this study, the Monark ergometer was modified. Racing-style handlebars were installed. The handlebars were rewelded for additional strength. Duval microswitches were mounted on both cranks in order to count pedal revolutions. Revolutions were registered on a modified Sanborn 100 ECG recorder. The ergometer was calibrated daily using a series of weights ranging from 0.1 kg to 2 kg. The resistance scale of the ergometer was rotated upward to accomodate higher static calibration of frictional resistance settings (4.0 to 10.0 kp). Cumming (1973) suggested that friction was relatively constant at speeds of 90 to 120 rpm for his 30 s power test on the Monark ergometer. A leg volume measurement tank used measured water displacements to 0.1 L at 20°C. Davies et al. (1972) indicated that limb volume by water displacement or anthropometry could replace leg muscle measurements by soft tissue radiography without much loss in accuracy. Katch and Weltman (1979) found the test-retest reliability of leg volume by displacement high ($r = 0.95$) with a standard error of measurement of $\pm 50\ cm^3$ (± 0.05 L).

Other apparatus used included John Bull Type (British Indicators Ltd.), a clinical balance and a steel anthropometric measuring tape. The hydrostatic weighing facility of the University of Alberta was used to measure body density.

Procedures

Introductory Session

The members of the experimental group (EG) came individually to the first session and were checked for general health and absence of athletic injuries. They were scheduled to come for exercise tests at the same time on each test day. Physical characteristics including anthropometric measurements were recorded: age, height, weight, leg volume and length, thigh and calf skinfolds and girths, and body density.

The volume of the right leg volume of each subject was determined by the technique of water-displacement. The tank was calibrated and measurements were taken at 20°C. Katch (1974) confirmed the accuracy of the technique on a test-retest basis (Mean difference = 10.1 ml; $r = 0.97$). Subjects squarely placed their leg only into the tank with inversion as far up the leg as possible (to the ischial tuberosity).

Leg length was defined as the distance from the greater trochanter to the lateral malleolus of the right leg. Measures of thigh girth and skinfold were made at the midpoint between the greater trochanter and head of the fibula. Measures of calf girth and skinfold were made at the greatest circumference of the calf of the unweighted right leg.

Total body fat was estimated from body density. The density of the body was determined by hydrostatic weighing with the volume of gas in the gastrointestinal tract assumed to be 100 ml for all subjects. Residual volume of the lungs was assumed to be 30% of the vital capacity. Vital capacity was measured on a Collin's vitalometer with the subject seated on the tank weighing chair (Novak, 1974). Percentage body fat was estimated from body density using the formula of Keys and Brozek (1953).

Experimental Test Sessions

The subjects undertook two power tests per day. Twenty-four hours elapsed between the paired tests. They were at least 2 hours postabsorptive before a test. The subjects were not informed of the frictional setting before a test but knew all tests were 30-35 s in duration.

Test Procedure

The following format was adhered to in each test. The saddle height was adjusted (and position noted for subsequent trials) so that the legs were almost fully extended at the bottom course of the pedal. The subject pedalled at 50 W for approximately 2 minutes at 60 rpm. The tester instructed the subject to increase speed until apparent maximum angular velocity, approximately 120 rpm, was reached. The tester called "go" and simultaneously increased the resistance quickly to the desired setting and turned on the revolution counter. It was necessary to start with no resistance because subjects had difficulty overcoming high inertia at the start with a load applied. As Katch (1973) found the delay from the command "go" to the setting of the proper resistance was approximately 1-2 s. The tester gave each subject strong verbal encouragement during each trial. Counts were made of each one half revolution of the crank for the test duration of 30-35 s. At the end of the trial, the subject was told to "stop", at which time the resistance was reduced to approximately 0.5 kp. The subject recovered for 2 to 4 minutes pedalling without load and then waited 20 minutes before he undertook the subsequent second trial. The ergometer was calibrated daily.

The maximal power output MPO and associated frictional resistance

(FMPO) was determined by stepwise 1 kp increments in F (starting at 4 or 5 kp) on successive trials till power output decreased. At that time, ½ and in most cases ¼ kp increments or decrements were applied on the remaining trials in a homing fashion till FMPO and MPO were found. The resistance setting, as determined by the Wingate protocol (FWIN), was randomly inserted in the stepwise increments. The last trial in the series was a retest of FMPO.

All records from the Sanborn recorder were 30-35 s in duration. The records of the number of revolutions for each trial were divided into 6 x 5 s intervals from 0.0 to 30.0 s. Rpm, absolute power (W) and relative power (W/kg) for the 5 s intervals and the mean power output for the 30.0 s period were recorded.

$$PO = \frac{F \times f_p \times 6}{6.12}$$

where:

PO = power output in Watts (W)

F = force or resistance setting in kiloponds (kp)

f_p = pedalling frequency or cadence in revolutions of the crank per minute (rpm)

MPO30s = maximal mean power output in 30 s, the peak and criterion value from the power curve plotted from all trials of one subject

MPO5s = highest 5 s power output during the MPO30s trial.

Individual power curves (power vs. force) were plotted for each subject.

Olympic Hockey Team Test Session

Stepwise multiple regression analyses of FMPO were produced, one based on a pretest trial at 5.0 kp and one based on leg volume and weight measurements. The latter was selected for testing the Canadian Olympic Hockey Team. Four months previous to the 1980 Winter Olympic Games, the team ($n = 23$) were given a single-trial test based on these 2 anthropometric parameters and procedures followed for EG. Body fat was estimated by the skinfold method (Keys and Brozek, 1953; Sloan, 1967).

Statistical Analysis

The statistical analysis of the results involved pairwise dependent t-tests for differences of means, Pearson correlations and stepwise multiple regressions. The latter statistical computations were made using a computer program from the University of Alberta Computer Services (B. Pinchbeck) from a procedure by Draper and Smith (1966). Significance was established at the alpha level of 0.05.

RESULTS

The physical characteristics of the 12 experimental subjects (Appendix A-I) included age 23.7 ± 3.3 years, weight 74.5 ± 8.1 kg, leg volume 11.2 ± 1.3 L and body fat 8.1 ± 2.6% (mean ± standard deviation). The submaximal power values (Appendix A-II) were the pretest power outputs at 5.0 kp 556.8 ± 39.1 W; at 6.0 kp, 582.1 ± 61.8 W; power output on the Wingate protocol, 588.4 ± 75.3 W, and the resistance setting for the Wingate protocol, 5.58 ± 0.61 kp. In the determination of the true maximum power outputs for the 12 subjects, 5 to 10 trials were necessary. An example of the power vs. time plot for each of the five trials necessary for subject #07 is given in Figure 1 showing successive 5 s measurements. Individual power/force curves for each subject (Appendix A-III) showed a characteristic MPO30s and optimal force to elicit MPO30s, FMPO, and included pretest and Wingate power/force values. The individual power curve data were pooled and presented in Figure 2 as a group power curve. For the experimental group, true FMPO was 7.21 ± 1.47 kp, MPO5s was 838.6 ± 127.4 W (11.27 ± 1.38 W/kg), MPO30s was 661.6 ± 96.6 W (8.91 ± 1.15 W/kg) and speed for the MPO30s trial, MV30s, was 94.5 ± 8.4 rpm (Appendix A-IV).

On the basis of a 1-tailed, pairwise dependent t-test, MPO30s with a mean of 661.6 W for EG, was found to be significantly greater ($p < .05$) than the power output, mean = 587.4 W, exhibited at the nearest resistance setting to the mean FMPO for the experimental group, 7.21 kp (Appendix B-I). The difference of mean was 74.2 W. No significant difference ($p > .05$) appeared between the mean F, 7.21 kp, and actual

Figure 1. The individual power/time plot: the relationship of power outputs at 5 s points to time on the various trial tests for the individual experimental subject #07. (The maximal power output trial is indicated by the symbol ●)

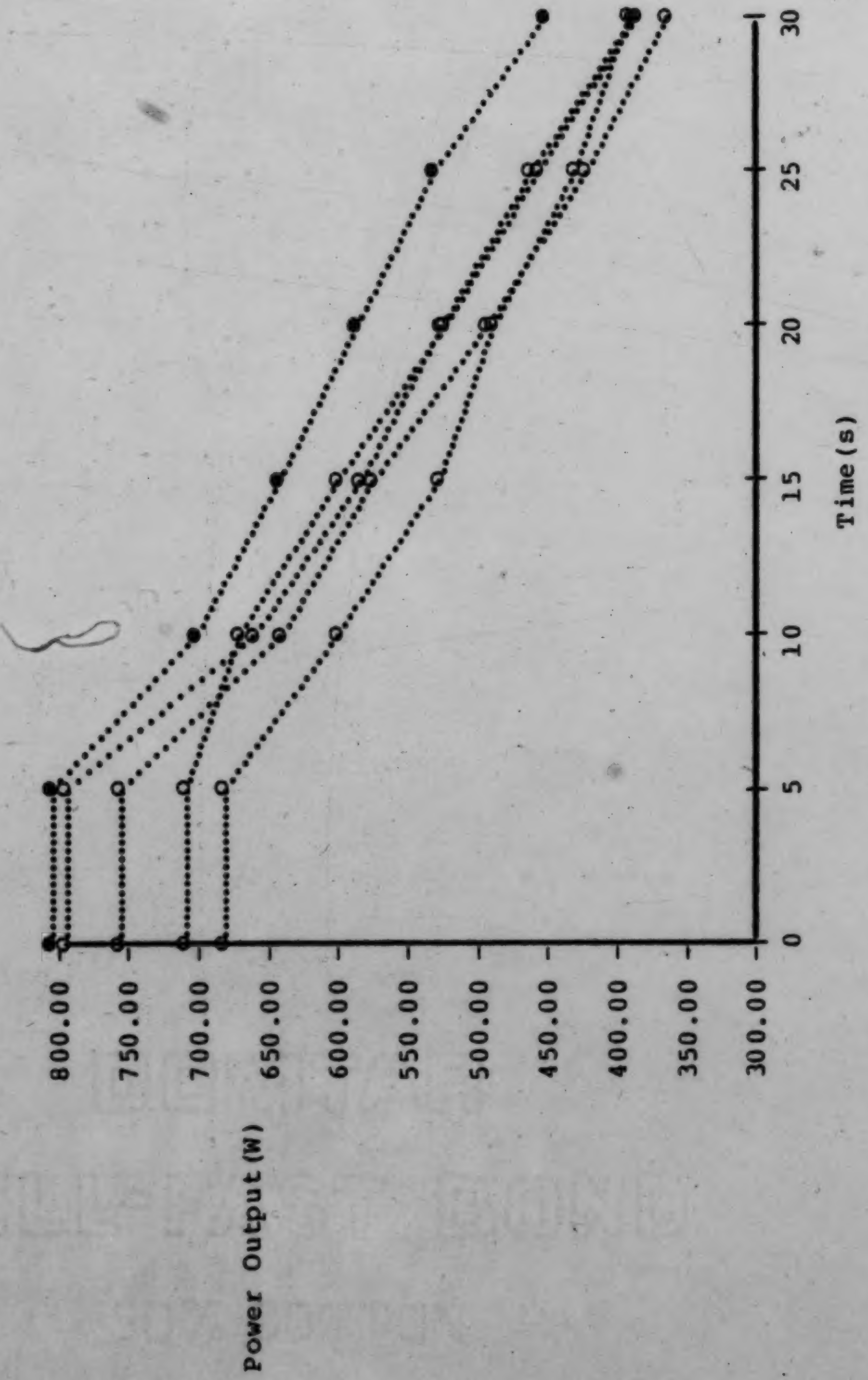
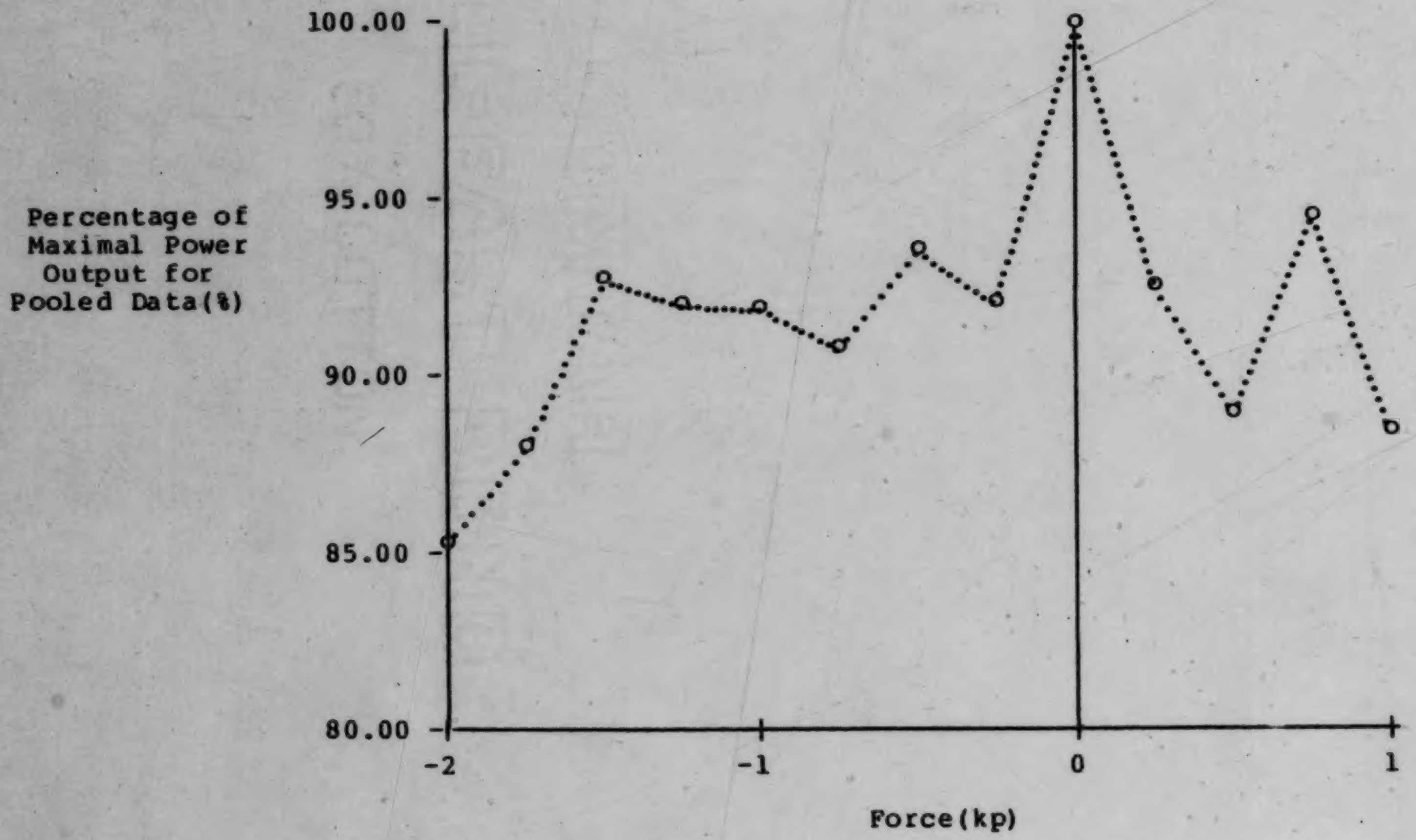

Power Output (W)
800.00
750.00
700.00
650.00
600.00
550.00
500.00
450.00
400.00
350.00
300.00
Time (s)
0
5
10
15
20
25
30

Figure 2. The group power curve: the relationship of the relative percentage of maximal power output and relative difference of force from force to elicit maximal power output (expressed in 0.25 kp increments and decrements from peak) for pooled data from the 12 experimental subjects


Percentage of Maximal Power Output for Pooled Data(%)
100.00
95.00
90.00
85.00
80.00
-2
-1
0
1
Force(kp)

F nearest 7.21 kp. Similarly, MPO30s was significantly greater ($p < .05$) than POWIN, the power output on the Wingate protocol with a mean of 588.4 W (Appendix B-II). The difference of means was 73.2 W and no significant difference appeared between the calculated resistance setting for the Wingate protocol (FWIN) and that actually used on the ergometer for the Wingate trial (FWINA). The difference between POWIN and MPO30s was as great as 146 W for high power athletes such as the university hockey players who had consistently higher MPO30s and MPO5s values than the university gymnast, distance runner, soccer player and physical education students. Mean power outputs for the various submaximal and maximal expressions of power increases as follows: PO5kp, PO6kp, PO at mean FMPO, POWIN and MPO30s. Similarly, the corresponding % CV, coefficients of variation (standard deviation ÷ mean, %) increased as follows: PO5kp, PO6kp, POWIN, MPO30s and PO at mean FMPO.

The test-retest reliability ($p < .05$) of MPO30s at FMPO was $r = 0.962$ and of MPO5s, $r = 0.912$ (Appendix C-I).

A hysteresis effect was noted in up and down calibrating the bicycle ergometer above 7.5 kp. The variation was approximately 0.1 kp from 7.5 to 9.0 kp and 0.2 kp at 9.5 kp. The latter variation in resistance setting, when calculated with the mean MV30s, 94.5 rpm, amounted to an error range in power output of 18.5 W or 2.8 % of the mean MPO30s, 661.6 W.

Stepwise multiple regressions by the method of Draper and Smith (1966) of true FMPO on the physical/anthropometric and pretest variables (see Appendix D-I for variable list and intercorrelations) yielded two formulae for estimating FMPO (see Appendix D-II for regression analyses). The first utilized anthropometric independent variables of leg volume and body weight:

$$\text{FMPO,kp} = -0.4914 - 0.2151\ (\text{Wt,kg}) + 2.1124\ (\text{Leg V,L}).$$

The standard error of estimate (SEE) was 0.83 kp and multiple $R = 0.873$ ($p < .05$). The second utilized a pretest power score at 5.0 kp:

$$\text{FMPO,kp} = -9.0166 + 0.0291\ (\text{PO5kp,W}).$$

The standard error of estimate was 1.02 and $R = 0.774$ ($p < .05$). Weight and leg volume used separately as independent variables did not estimate FMPO as well as the above two estimations of FMPO ($R = 0.506$, $p < .10$ and $R = 0.743$, $p < .05$ respectively). Noted was the high degree of association between these variables themselves, $R = 0.921$.

The study was limited in sample size. Kerlinger (1973) proposed that a shrinkage formula (Appendix D-III) be applied to R^2, the part of the Y sum of squares associated with the regression of Y on the independent variables to make a more conservative estimate of the variance accounted for. Thus R^2 for the anthropometric estimate reduces from $0.873^2 = 0.762$ to 0.709 and for the pretest estimate from $0.774^2 = 0.599$ to 0.559.

Analysis of residual errors of prediction and of other statistics were performed on the data to discern violations of the assumptions of multiple regression. The relationship between MPO30s and true FMPO is shown in Figure 3. Similarly the relationships between true FMPO and the estimated FMPO's for the anthropometric and pretest data are shown in Figures 4 and 5. The slopes of the predictive formulae were greater than zero (Appendix D-II).

Examinations of the residual plots for true FMPO minus estimated

Figure 3. Relationship of true maximal power output for 30 s and true force to elicit maximal power output for the experimental group (n=12)

$Y=175.5684 + 67.4243X$

$R=0.945$
$SEE=34.567$

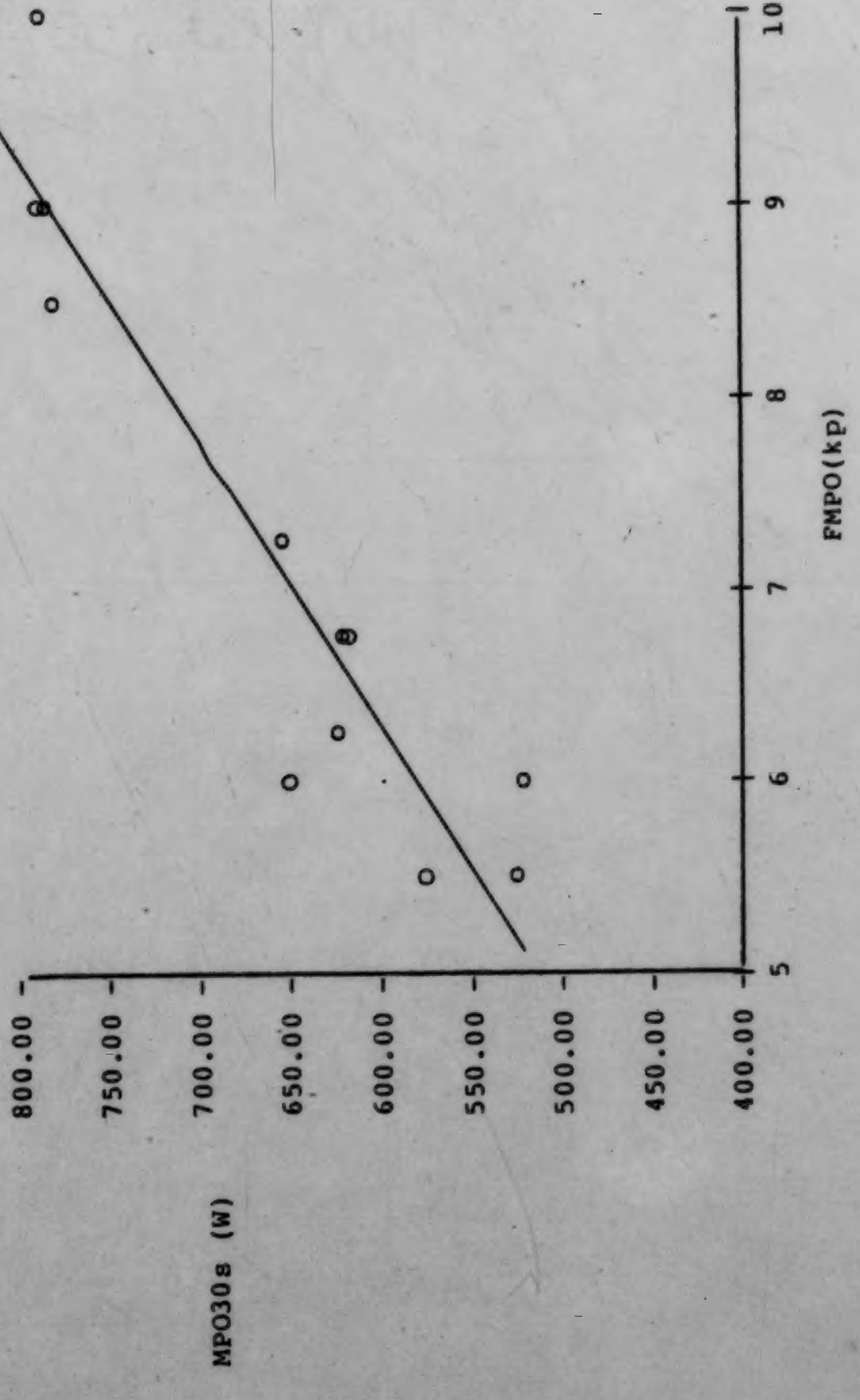

MPO30s (W)
800.00
750.00
700.00
650.00
600.00
550.00
500.00
450.00
400.00
5
6
7
8
9
10
FMPO(kp)

Figure 4. Relationship of true and estimated force (based on anthropometric data) to elicit maximal power output (W) for experimental group (n=12)

$Y=-0.0002 + 1.0000X$

$R=0.949$
$SEE=0.470$

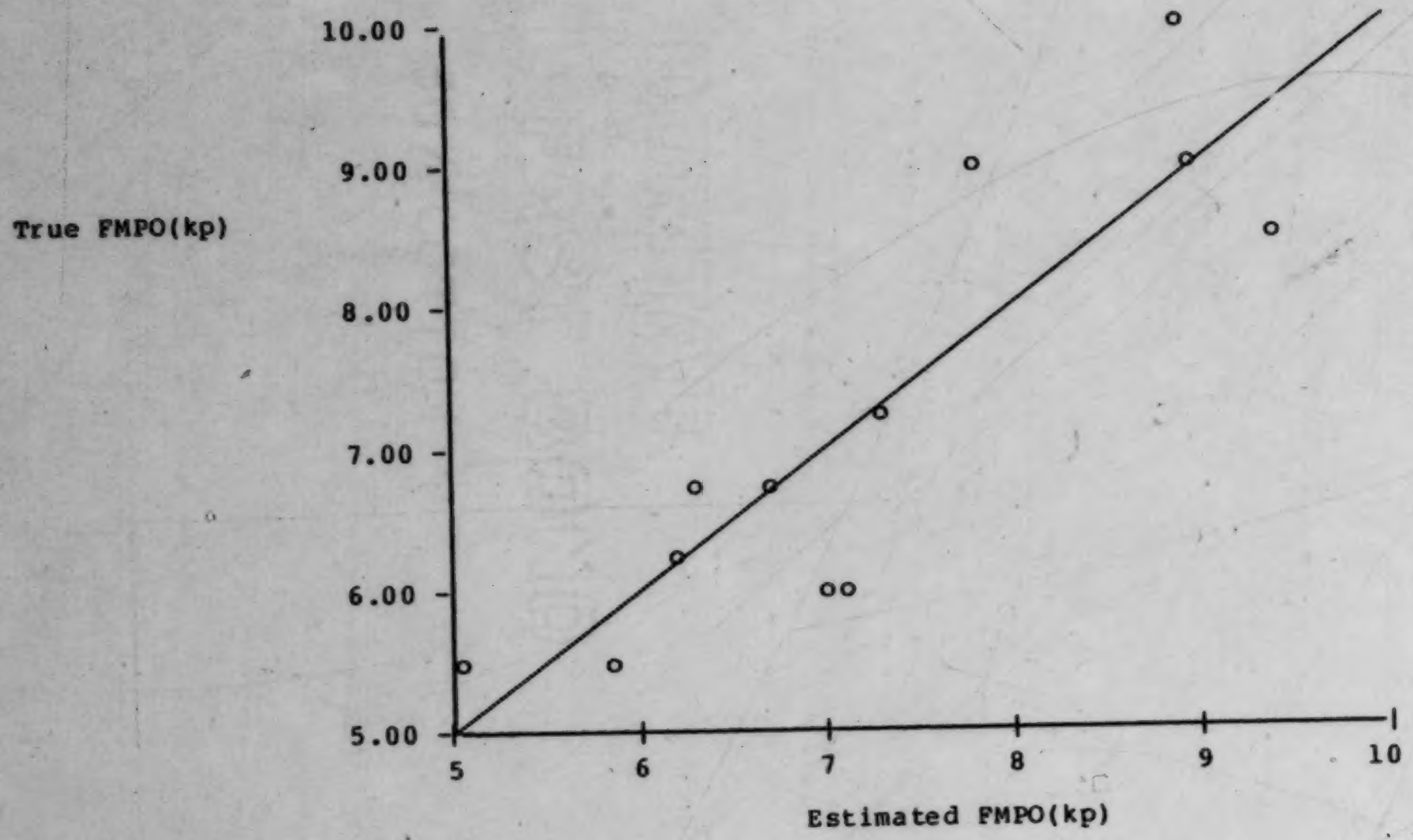
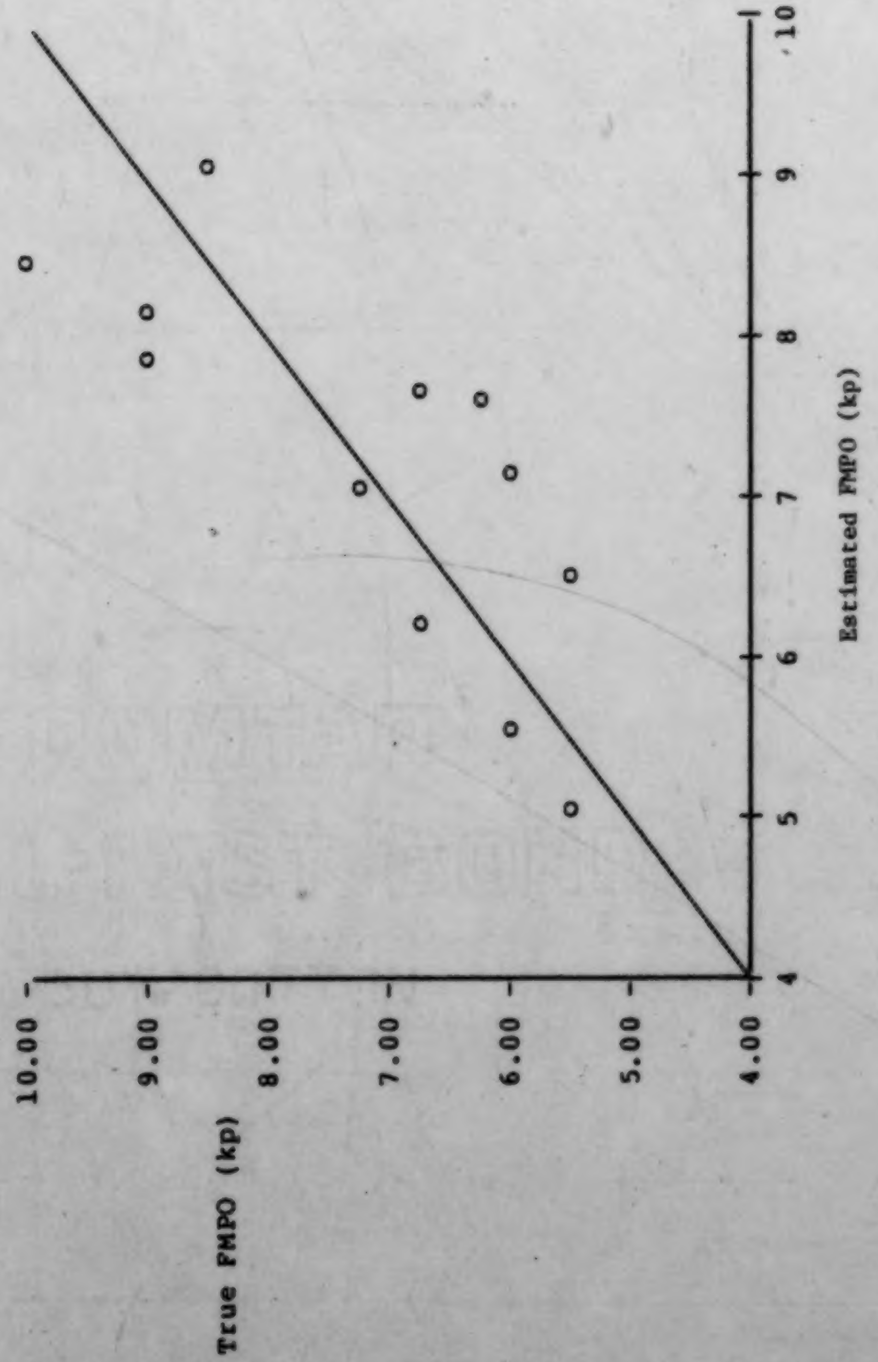

True FMPO(kp)
10.00
9.00
8.00
7.00
6.00
5.00
5
6
7
8
9
10
Estimated FMPO(kp)

Figure 5. Relationship of true and estimated force (based on pretest data) to elicit maximal power output (W) for experimental group (n=12)

$Y=0.0114 + 1.0013X$

$R=0.841$
$SEE=0.802$


True FMPO (kp)
10.00
9.00
8.00
7.00
6.00
5.00
4.00
Estimated FMPO (kp)
4
5
6
7
8
9
10

FMPO versus FMPO, weight, leg volume and P05kp and of unidimensional scatter plots for normality of distribution of errors of the two estimations of FMPO were undertaken (Appendix E-I to V). No severe departures from normal were seen.

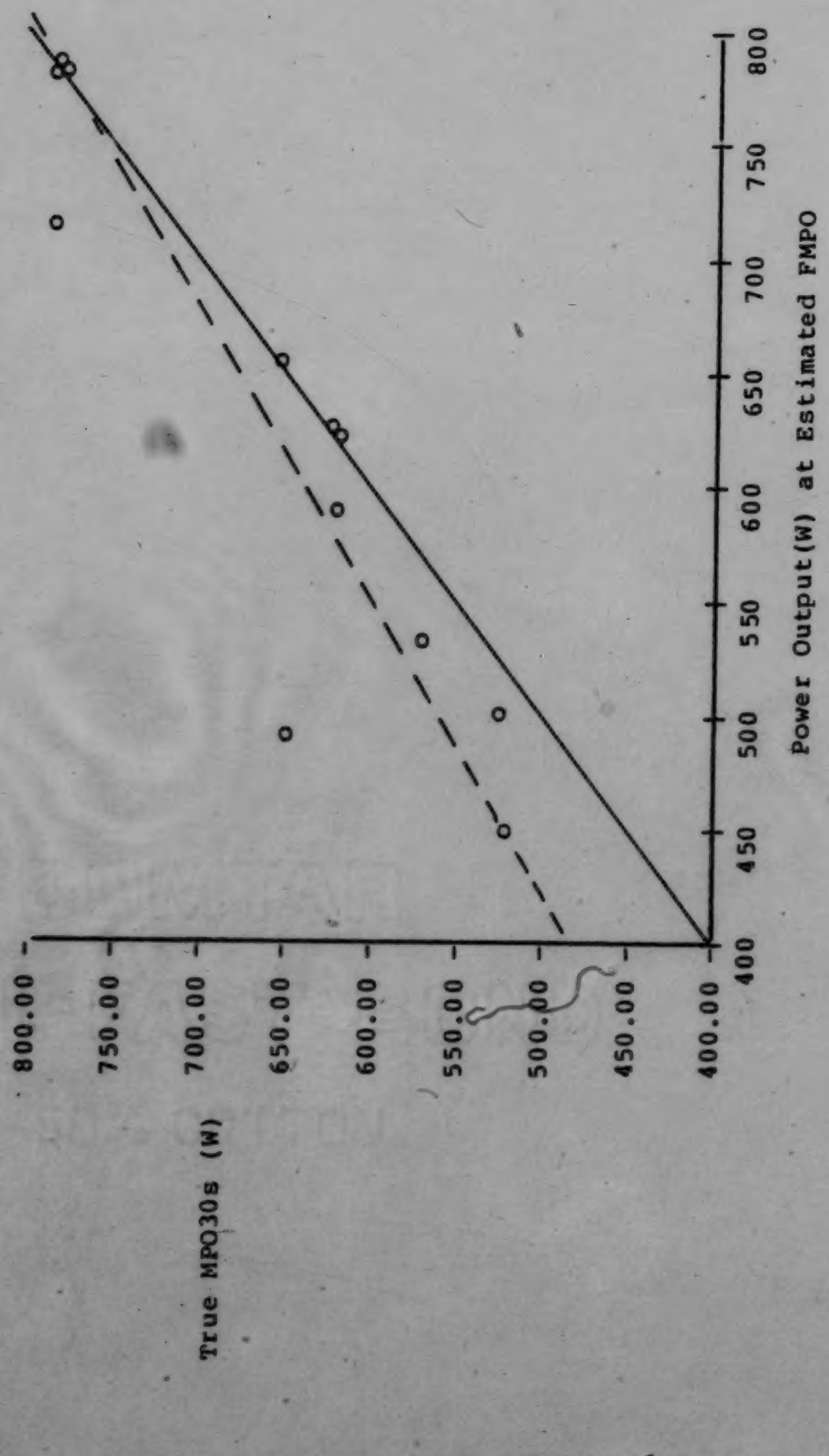
The linear relationship was reviewed between the true and estimated FMPO (anthropometric), the stimulus for MPO30s, in Figure 4; the spread of points about the identity line is even. However, the linear relationship in the response curve, true MPO30s versus power output at estimated FMPO in Figure 6, lies above the identity line. Readjustment of the identity line by increasing power values by the difference of means between true and estimated MPO30s shows a more even spread of points except for one outline (Appendix E-IV), with an outlying score of 158.5 W in subject 02. This subject had the highest speed of pedalling, MV30s - 110.6 rpm, at MPO30s, of all the experimental group.

The application of the anthropometric test protocol to the testing of the Olympic Hockey Team (n = 23) yielded higher FMPO and power values than in the experimental group: FMPO = 9.77 ± 1.61 kp, MPO5s - 943.0 W, MPO30s = 775.1 ± 74.6 W and MV30s = 86.5 ± 12.9 rpm (Appendix A-V(b)). Eight players had estimated FMPO's exceeding 10.0 kp, the limit of the current resistance scale, and therefore pedalled at 10.0 kp. The mean MPO30s for the Olympic team, 775.1 W, exceeded that of the experimental group, 661.6 W, but was close to the mean of the four highest power scores of the experimental group (those of the four varsity hockey players), 785.8 W. The mean for the non-hockey experimental group (n = 8) was 599.5 W. Speed of pedalling at MPO50s was 86.5 rpm, less than 94.5 of the experimental

Figure 6. Relationship of true maximal power output for 30 s and the power output exhibited at the estimated FMPO (based on the anthropometric data) for the experimental group (n=12)

$Y=174.1496 + 0.7773x$

$R=0.919$ $SEE=41.748$


True MPO30s (W)
800.00
750.00
700.00
650.00
600.00
550.00
500.00
450.00
400.00
400
450
500
550
600
650
700
750
800
Power Output(W) at Estimated FMPO

group. However, several players (07, 19, 20) had high pedalling rates for 30 s of 107.7, 126.3 and 103.7 rpm. Player 20 had the highest absolute and relative power of the experimental group and hockey team, 915.0 W and 11.35 W/kg. Player 19 had the highest 5 s pedalling speed of 159 rpm at the start of his trial.

The mean weight leg volume and body fat of the experimental group were smaller than those of the hockey team. However variations in values for the experimental group were somewhat higher (Appendix A). The relationships of MPO30s on leg volume and body weight for the experimental group are illustrated in Figures 7 and 8 respectively. The Y intercept of the body weight graph was almost seven times higher than that on the leg volume graph.

Significant associations ($p < .05$) existed between MPO30s and MPO5s for the experimental group, $r = 0.970$ and for the hockey team, $r = 0.893$ (Appendices A-IV and A-V(B)).

Figure 7. Relationship of maximal power output for 30s and leg volume for the experimental group (n=12)

Y=29.5343 + 56.2640X

R=0.743
SEE=70.880

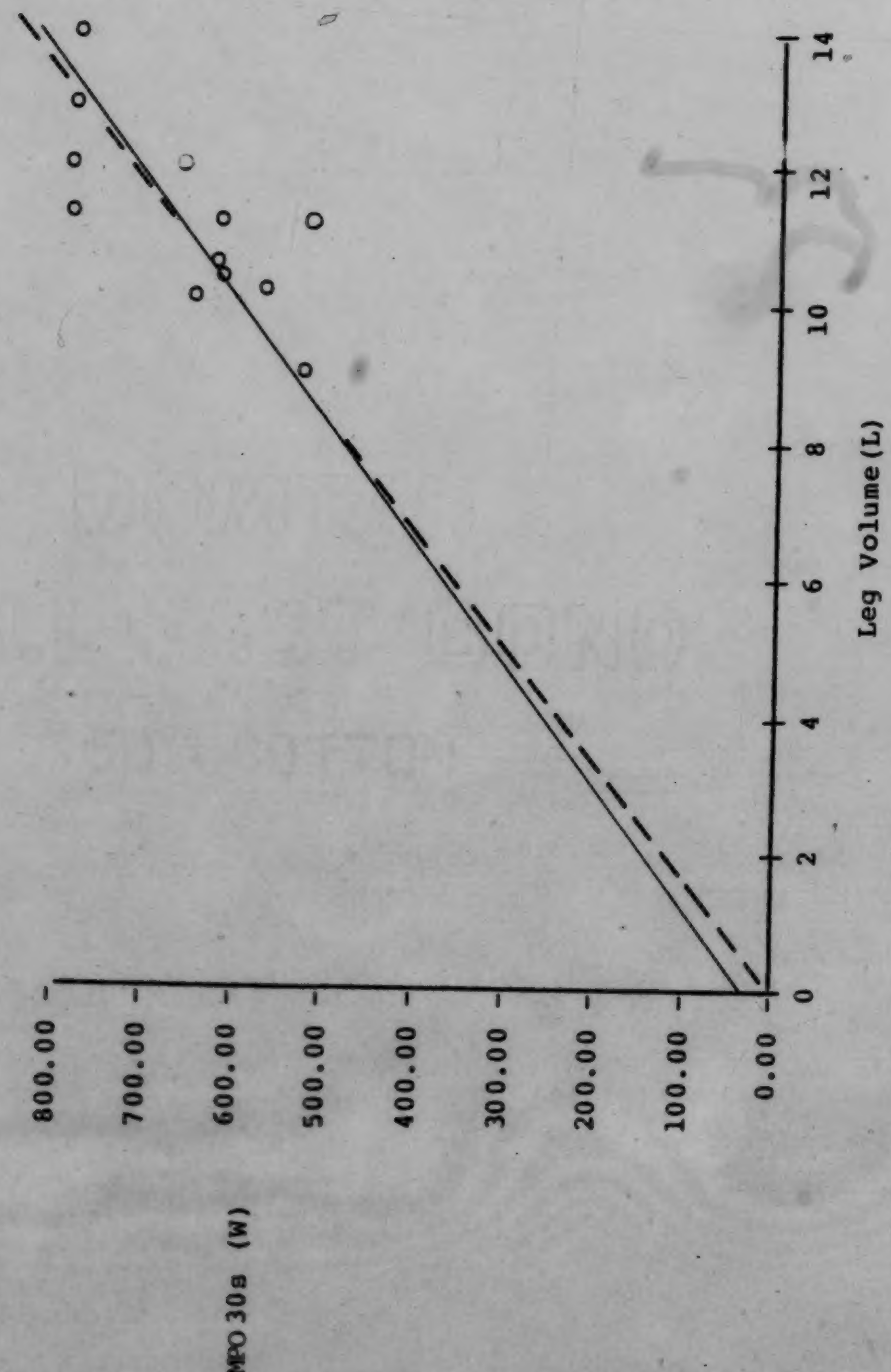
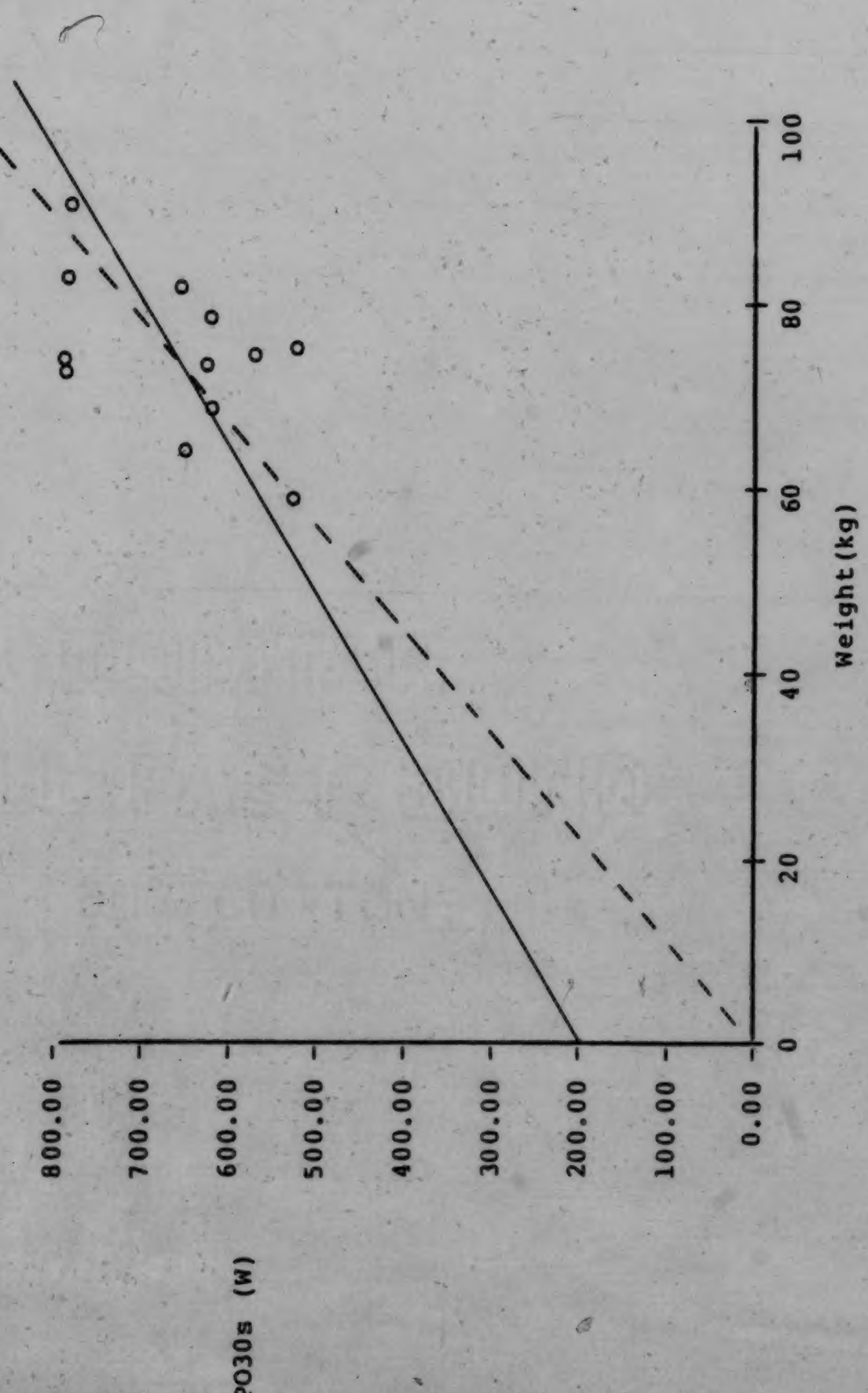

MPO 30s (W)
800.00
700.00
600.00
500.00
400.00
300.00
200.00
100.00
0.00
0
2
4
6
8
10
12
14
Leg Volume (L)

Figure 8. Relationship of maximal power output for 30s and body weight for the experimental group (n=12)

$Y=196.3048 + 6.2430X$

$R=0.522$

$SEE=90.267$


MPO30s (W)
800.00
700.00
600.00
500.00
400.00
300.00
200.00
100.00
0.00
0
20
40
60
80
100
Weight(kg)

DISCUSSION

Power output on the bicycle ergometer is a function of the resistance setting or force and rpm or velocity of pedalling. Within a 30 s all-out power test, a unique optimal product of force (FMPO) and velocity (MV30s) exists to elicit an individual true maximal power output (MPO30s) as exemplified in the individual power curves. The similar relationship with the group pooled data in Figure 2 also shows the characteristic peak or maximal power elicited from an optimal resistance setting and optimal rpm, not necessarily extreme values for either. Similar findings are reported by Sjøgaard (1978) who investigated pedalling at 70 and 100% of $\dot{V}O_2$max and found that a force-velocity curve must be mapped for each activity such as bicycle exercise and that discrepancies exist between Hill's classical force-velocity curve and experimental curves. He suggested a discrepancy could be due to negative work being done before each positive cranking phase. More of the negative work could be used at high pedal frequencies resulting experimentally in a levelling off of the force-velocity curve rather than an intercept as in the Hill equation. Also increased prestretch and release of elastic energy were possible with increasing speed.

The force setting of 5.5 to 10 kp in the experimental group is high in comparison to force levels used in aerobic testing. In brief tests, such as of single efforts of maximum voluntary contraction (MVC), one can see even higher force settings. For example, Sjøgaard (1978) indicated that the force of a single maximum voluntary contraction for his 13 male adult subjects ranged from 230-420 kp. Repeating contractions over a period of time where endurance is limited to 30-40 s diminishes the force of each muscle contraction to approximately 50% of one MVC (Borg, 1975). Similarly, the general hyperbolic-like relationships exist for the power (force x velocity) versus force curves exemplified in the current study.

Force on the crank reflects the resistance setting set on the bicycle ergometer. Sargeant and Davies (1977) found mean peak forces at the cranks linearly related (0.98, $p < .001$) to power outputs below $\dot{V}O_2$max (at 50 rpm). Work at the cranks may actually be approximately 50 W (5% higher than the setting itself) due to frictional losses, that increase with workload. While study of high speed force recordings at the cranks in anaerobic tests are needed, settings were deemed suitably accurate in the current study. Hystersis effects in calibration at high resistance settings were minimal.

Various methods of administering force setting for power tests are available to a tester. Selection of an absolute setting such as 5.0 or 6.0 kp, a mean fixed setting based on experimental evidence from a study such as the current investigation, a relative force setting based on pretest functional or anthropometric data or determination of criterion force and power are previously used approaches. An absolute setting may not allow expression of maximal power for the individual. In the current study, three of the twelve experimental subjects actually decreased power output with the increase in setting from 5.0 to 6.0 kp. The mean fixed setting for the group and the Wingate force setting were similarly significantly lower than true maximum power. The force and power values from the literature, as surveyed in Table 1, evidence lower values. Previous approaches to power testing protocols are lacking, particularly for individuals of higher anaerobic power. Subjects were most often not given an optimal or heavy enough loading for the test.

The reliability of MPO30s is high, similar to the high levels for other power tests indicated in Table 1. Tests and retests were completed within 3 weeks in the current study. Therefore, although there seems to be reproductibility within a few weeks, stability of the measure over months and alterability by means of training have not been investigated.

The stepwise regression technique conveniently yielded simple estimations of FMPO. The number of independent variables was low for each expression. The anthropometric estimation necessitated not only the weight variable as found in the Wingate estimate but also leg volume, equally expedient variables to be measured. The high multicollinearity of leg volume and weight ($r = .921$) would be a problem in the regression except that each variable entered in the expression is tested for significance of its inclusion to the regression equation. Also for the variables already in the equation, the significance of their continued inclusion in the equation is tested at each step. Davies et al. (1972) found a correlation $r = 0.93$ ($p < .05$) between weight and leg volume in children of 6-16 years. Sample size affects both estimates almost equally and was a limitation of the study.

The assumptions of the multiple regression analysis appear to have been met. The models of FMPO regressed on PO5kp, leg volume and weight appear to be linear and significantly greater than zero. The residual errors appear to be independent, to have a zero mean and homogeneity of variance. The anthropometric residuals are somewhat more normally distributed than the pretest ones. The anthropometric estimate requires a scale and volume tank while the pretest requires only the ergometer. The former is preferred because of superior correlation and normality, less error of prediction, simplicity of pretrial measurements and absence of pretest fatigue and recovery time. All 30 s power trials, including pretest trials, were very severe and the minimal number of trials, preferably only one, is best received by subjects.

The use of formulae to estimate FMPO allows options in maximal power testing as indicated in Table II. Bracketing the estimated FMPO trial with runs ± 0.5 kp to span most of the residual error of the method would improve the estimate and define part of the power curve. A post test analysis of MV30s for the trial adds further information as to whether subsequent trials should have increased or decreased resistance settings. With test option 2, it is suggested that second or third trials, subsequent to trials with MV30s below 80 rpm have resistance settings decreased; conversely those above 100 rpm have resistance settings increased. However, criterion accuracy necessitates multiple trials. Considering the standard error of estimate of the anthropometric method (option 1a), 0.829 kp, as a percentage of the mean response, 7.21 kp (Draper and Smith, 1966), the percentage calculated, 11.5%, compares favourably with 10-15% error of prediction of $\dot{V}O_2$max from the Astrand 6 minute submaximal aerobic test and nomogram (Astrand and Rodahl, 1970).

Elite hockey players have high development of muscular leg power. The Olympic and university hockey players (excluding goalies) had consistently higher power scores on the 30 s test than physical education students and other university athletes studied. The specificity of power is evident. Individual high values such as 915 W and 11.35 W, in the same

TABLE II

MAXIMAL POWER TESTING OPTIONS

	Accuracy Desired	Force-Setting	Number of Trials
Option 1.	Estimated	a. Anthropometric FMPO b. Pretest FMPO	1 1 + 1
Option 2.	Estimated	a. Anthropometric FMPO ± 0.5 kp b. Pretest FMPO ± 0.5 kp	3 3 + 1
Option 3.	Criterion	Determine individual power curve	5 - 10

Olympic hockey player indicate high power values are possible in elite power sports and are not dictated by a gross body dimension, such as weight, alone.

The apparent high power evidenced by hockey players is associated with the nature and time course of the game. Green, Bishop, Houston, McKillop, Norman and Stothart (1976) performed time-motion and physiological studies on varsity hockey players. They noted that forwards and defensemen had a continuous playing time per shift on the ice of 39.7 s. Blood lactic acid levels after periods of play were elevated 4 to 5 fold. The anaerobic nature of ice hockey and the similarity of duration of effort between hockey and the 30 s power test undoubtedly account for in part the elevated power levels evidenced by the elite hockey players in the present study.

The time of the year when elite athletes are tested for power may dictate levels attained. Hockey players may show specific adaptation to their sport. Green, Thomson, Daub, Houston and Ranney (1979) indicated that fibre distribution, fibre type and metabolic profile of elite hockey players prior to a season of play are within the range found for the normal untrained population. Size of FT fibres and conversion of FTb to FTa fibres is known to occur with training. The Olympic Hockey Team was tested 4 months before the Winter Olympic Games and approximately 3 months into the formal training session as a team. It is conceivable that higher power outputs would have been evidenced with peaking in training immediately prior to completion. Monitoring of pretraining, training and competition levels would allow the trainer and coach insights into the training needs of individual players.

Body form is related to function in the current study as FMPO to weight and leg volume. Inclusion of leg volume and body weight variables probably reflect leg hypertrophy and large absolute body dimensions of individuals capable of high power output. Katch (1974) showed in male college students performing heavy intensity work for 2 minutes on a bicycle ergometer that body weight, leg volume and leg weight accounted for approximately 41, 36 and 26% of the common variance in total work output respectively; when work becomes more intense with increasing time or load, factors such as body weight, taken on added importance in determining individual differences in work output. Body weight and leg volume accounted for 27 and 55% of the variance in power output in 30 s. Large muscle mass takes on more importance with increasing intensity of exercise. Saltin and Karlsson (1971) suggested that approximately 10, 15, 20 and 25 kg of the body's muscle mass are engaged in bicycle exercise at workloads demanding 25, 50, 75 and 100% of $\dot{V}O_2$max. The higher intensity of the 30 s all-out test would necessitate high muscle mass involvement from not only the legs but apparently the trunk, shoulders and arms. Movement stabilization and general twisting and lateral torquing of the handlebars of high power athletes necessitated strengthening the dropbars and frame of the conventional bicycle ergometer.

Not all anthropometric measurements meaningfully contribute to estimations of performance. Adams (1967) investigated 60 adults from 20 to 52 years of age cycling at 16 km/h. The multiple regression analysis confirmed the dominant effect of total body weight in the prediction of energy expenditure for the ride. Neither age, height, body surface area, lean body mass, fat weight or tricep skinfold contributed significantly. The total body fat and skinfold independent variables in the present study were not significant inclusions in model formulae, despite the heterogenity of leg and total body composition and heterogenity of anaerobic fitness of the active to highly trained experimental group.

The relationship of power to leg muscle and overall body size has been established in a range of anaerobic and aerobic power tests. In comparing maximal power outputs of adults on maximal jumping stair running and aerobic bicycle exercise, Davies (1971) found significant relationships between leg volume and weight with various expressions of power in various ages of subjects. However, subjects older than 35 years showed a complete lack of association between indices of body composition and maximal aerobic power. Davies postulated that muscle mass for a given body size remained unchanged with age but muscular energy stores and utilization declined. The experimental group of the current study was comprised of young male adults from 21 to 33 years; the somewhat older outliers, 27 and 33 years did not differ from the nonhockey experimental group. Despite the high variation in body fat, the group was lean (3.2 to 11.8%). The heterogeneity of fat within the lean classification still did not influence the estimation of FMPO. Thus, the applicability of the FMPO estimation to subjects is limited somewhat to young male adults of average leanness so that fat and age are not larger contributors to leg volume or body weight. Older, less lean and more sedentary subjects would find much less benefit from high power evaluations as from evaluations of aerobic power and body composition in any case.

Anaerobic training may not only alter power levels of subjects but anthropometric measures upon which resistance settings can be based. Sprint training can result in gross changes in body composition and cellular adaptations. Thorstensson, Sjödin and Karlsson (1975) investigated the effects of sprint training on 4 healthy male subjects. Aside from increases in performance in vertical jump, Margaria stair run, leg strength and endurance, they showed increases in total phosphagens, ATP splitting and resynthesizing enzymes, fibre areas of both FT and ST types, leg volume and weight but no change in muscle fibre type distribution. They reasoned that increased fibre area could account for muscle hypertrophy based on increased leg volume. Cellular and anthropometric changes with training would predicate the retest of anaerobic power not only on the initially established FMPO but possibly on a new FMPO based on retest weight and leg volume values.

The shape of the individual power versus time curves shown in Figure 1 followed that of Katch et al. (1977). Highest peak power (MPO5s) in a single trial was invariably in the first 5 s followed by a slow drop in the curve over 30 s. Similar to the stair run of Margaria (1966), the peak power (MPO5s) in a MPO30s trial run probably reflects mainly phosphagen-splitting rate whereas MPO30s probably reflects both phosphagen and glycolytic or total anaerobic power. Further study will be necessary to quantify the involvement of energy pathways and appropriateness of the 30 s time frame for anaerobic capacity tests. Caution is suggested in using the MPO5s score as a true maximal value as it is dependent on the MPO30s and highly correlated to it. A unique force-velocity relationship undoubtedly exists for a true MPO5s for each subject.

The question of generality of the test, its applicability to cyclists and noncyclists, must be considered. Astrand and Rodahl (1970) remarked that Olympic medal cyclists and untrained persons have the same mechanical efficiency at submaximal loads. Relatively uncomplicated activities such as running, walking or cycling have only slight increases in efficiency with training but the increase is less than the variability between individuals. High anaerobic involvement, high pedal speeds and loads may alter efficiency. Gladden and Welch (1978) noted the efficiency of heavy work (100% $\dot{V}O_2$max) was lower than that of light work, not due to energy shortage but possibly due to decreases in muscle efficiency and the metabolic overhead of stabilizing body parts, work of the heart and respiratory muscles. Therefore comparative studies on cyclists and noncyclists for mechanical, thermal and biochemical efficiency and habituation differences at 30 s maximal power levels is indicated.

Speed and force mathematically contribute to power calculations jointly. However, speed may be less deterministically a factor in 30 s all-out trials. Although force (FMPO) was highly and significantly ($p < .05$) associated with maximal power, no absolute or relative, 30 s or 5 s power outputs for the experimental group or the hockey team evidenced significant associations with MV30s (with the exception of the weight-relative MPO30s for the hockey team). Jointly, speed and force account for all the variance of power but apparently speed is a dependent factor rather than a singularly independent factor of power as defined in the current study. Thus specifying test stimuli in terms of specific resistance settings, with all-out cadence, seems warranted.

From the study of the association between physiological form and function comes reliable formulae for estimating resistance settings to elicit maximal power on a 30 s all-out anaerobic power test on the bicycle ergometer.

Implications and Applications

Test properties need to be realized before widespread application of the test to groups at large. Margaria et al. (1966) listed advantages and disadvantages for an anaerobic power test, particularly for their stair run. Advantages:

(1) The test should have a well-defined character, that is, power.
(2) No particular knowledge or skill is required by the operator.
(3) No expensive apparatus is needed.
(4) The exercise requires no particular skill or training by the subject.
(5) The test does not lead to exhaustion.
(6) A large fraction of the muscle mass is incorporated.

(7) The test has wide application in population surveys.

Disadvantages:

(1) The test depends on the subject being willing and unhandicapped.

(2) It measures leg and lower trunk power.

The current MPO30s test seems to satisfy condition (1). The time frame of 30 s permits power development through glycolytic and phosphagen energetics. The appropriateness of 30 s for characterizing total anaerobic capacity remains to be investigated. Analysis and description of fibre type and areas, terminal muscle and blood pH and lactate levels, enzyme involvement of ATPase, MK, CPK and LDH isozymes, initial phosphagen and glycogen levels and depletion and recovery oxygen will lead to the validation and understanding of the underlying physiological mechanisms of anaerobic power.

The MPO30s test does lead to exhaustion. Therefore the results of multiple trials and other exercise tests in a brief period of time could mitigate expression of true MPO30s. The testing options listed reduce the number of trials at the expense of accuracy. Trained individuals recover quickly and the one-trial approach with a large group such as the Olympic Hockey Team is well-received.

The development of norms and application of the test to population surveys can be realized after cross-validation of the test with another similar experimental group.

Fitness testers should give consideration to the absolute or relative expression of maximal anaerobic power for populations. A logical and physiological problem sometimes arises in making absolute physiological responses relative by dividing the response by a body parameter such as weight, height or surface area. Part of the fallacy can be in using a ratio of function and build (form) when values are not equidimensional (Kleiber, 1950). $\dot{V}O_2$ and weight are assumed to be (Katch, 1973). Further investigation into the physiology of anaerobic power is necessary before suggesting dimensions for it. Part of the problem lies in assuming the ratio and regression expressions of power (for example MPO30s/wt and weight-regressed MPO30s/wt) are the same. Although some physiological ratio and regression relationships are consistently very close, as with BMR and body surface area (Tanner, 1949), they need not always be. The ratio of power to some body dimension implies that on a graph, the line representing the ratio passes through the origin as well as through the point of the two means of $\dot{V}O_2$ and body weight. That is the ratio assumes a perfect linear correlation between power and the body dimension and the two variables are directly proportional (Katch, 1973). This is obviously not always the case and can lead to erroneous conclusions particularly in population comparisons (Wyndam, 1974) and correlation analyses (Katch, 1973). In Figures 7 and 8, power is expressed relative to weight, the most common relative expression and relative to leg volume. Note that the leg volume expression for the experimental group ($n = 12$) would appear to be a better comparative standard because (a) the Y-intercept is 6 to 7 times closer to the origin, (b) the correlation is higher and SEE, lower, (c) the ratio of % CV MPO/% CV anthropometric standard is closer to one for leg volume than weight, where one indicates ratio and regression scores are the same (Katch, 1973) and the ratio (broken line) and regression lines are nearly coincident. (No statistical tests of difference were done on the limited amount of observed data). Caution is suggested in adapting a relative anthropometric standard until the nature and dimensions of anaerobic power are more fully understood and more individuals have been tested.

The properties of the Margaria test are parallel to the properties of the current test. Further internal investigation of the physiology of power and external application with normative data on widely varying groups will elucidate an important area in sport and work science.

SUMMARY AND CONCLUSIONS

The purpose of this investigation was to derive formulae for the estimation of resistance settings on the bicycle ergometer that would allow subjects pedalling all-out for 30 s to demonstrate maximal power output.

Twelve active to highly trained young male adults were measured on a series of lower limb and total body anthropometric measures. They were also tested in a series of 30 s all-out ergometer tests. Force settings used were absolute settings at 5.0 and 6.0 kp, a weight-relative setting from the Wingate Institute and a series of increasing settings till maximum power was demonstrated. A general individual and group curve which was concave downward resulted from which true maximal 30 s power outputs (MPO30s) were established.

MPO30s proved to be significantly greater than the power output at the fixed mean resistance setting for the experimental group and greater than the Wingate power output ($p < .05$).

The MPO30s elicited from the FMPO, the resistance setting from the power curve for MPO30s, proved reliable on a test-retest basis ($r = .96$, $p < .05$). Therefore predictive equations for FMPO were established by stepwise multiple regression on the anthropometric and pretest submaximal power outputs. The first utilized power output (W) at 5.0 kp: FMPO = -9.0166 + 0.0291 (PO5,kp) with R = 0.774. The second was derived from weight and leg volume: FMPO = -0.4914 - 0.2151 (WT,kg) + 2.1124 (LEGV,L) with R = 0.873. Application of the latter protocol to the Canadian Olympic Hockey Team resulted in a power output of 775.1 ± 74.6 W with a ceiling output of one player being 915 W, 11.35 W/kg.

In conclusion, a reliable testing tool is available for determining maximal anaerobic power on a single 30 s all-out trial on the bicycle ergometer.

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APPENDIX A

APPENDIX A-I	Physical Characteristics of Experimental Subjects
APPENDIX A-II	Submaximal Power of Experimental Subjects
APPENDIX A-III	Individual Power Curves
APPENDIX A-IV	Maximal Power of Experimental Subjects
APPENDIX A-V	Physical and Functional Characteristics of the Olympic Hockey Team

APPENDIX A-I(a)

Physical Characteristics of Experimental Subjects

Subject	Age (yrs)	Weight (kg)	Leg Volume (L)	Body Fat (%)	Athletic Classification
01	21	74.1	12.0	4.9	university hockey
02	21	64.0	10.1	6.5	university distance running
03	22	90.5	13.9	10.5	university hockey
04	24	81.6	12.0	8.3	university hockey (goalie)
05	22	82.9	12.9	10.4	university hockey
06	33	78.4	11.2	11.6	physical education
07	27	68.7	10.4	3.2	physical education
08	22	74.4	10.2	6.7	university soccer
09	24	73.1	10.6	11.8	physical education
10	22	75.1	11.2	8.5	physical education
11	22	59.0	9.0	8.0	university gymnastics
12	24	72.5	11.3	6.3	university hockey
Mean	23.7	74.5	11.2	8.06	
SD	3.25	8.08	1.27	2.57	
% CV	13.7	10.8	11.35	31.9	
Range from	21	59.0	9.0	3.2	
to	33	90.5	13.9	11.8	

APPENDIX A-I(b)

Physical Characteristics of Experimental Subjects

Subject	Height (cm)	Pondural Index $(\sqrt[3]{kg}\bullet 1000\bullet cm^{-1})$	Leg Length (cm)	Thigh Girth (cm)	Calf Girth (cm)	Thigh Skinfold (mm)	Calf Skinfold (mm)
01	167.6	25.06	81.0	55.0	39.0	12.2	5.4
02	176.5	22.66	86.0	50.0	36.0	8.8	4.0
03	179.1	25.07	86.5	60.0	40.0	11.1	6.2
04	179.1	24.22	86.5	56.5	38.5	10.8	6.6
05	179.1	24.35	86.5	59.0	40.5	10.0	6.0
06	186.7	22.93	84.3	50.5	37.5	8.4	4.4
07	175.3	23.37	80.0	48.5	35.0	7.1	7.2
08	181.6	23.16	93.0	55.5	37.5	7.3	3.8
09	170.2	24.67	79.5	56.0	38.0	10.8	9.0
10	170.8	24.70	81.0	53.0	38.0	10.0	6.6
11	172.7	22.54	89.0	47.0	33.5	6.4	6.0
12	175.3	24.14	80.0	53.5	36.5	7.8	7.1
Mean	176.16	23.91	84.4	53.7	37.5	9.22	6.02
SD	5.14	0.89	4.05	3.88	1.93	1.77	1.42
% CV	2.9	3.7	4.8	7.2	5.1	19.2	23.5
Range from	167.6	22.54	79.5	47.0	33.5	6.4	3.8
to	186.7	25.06	93.0	60.0	40.5	11.1	9.0

APPENDIX A-II

Submaximal Power of Experimental Subjects

Subject	PO30s at 5 kp (W)	PO30s at 6 kp (W)	FWIN (kp)	FWINA (kp)	POWIN (W)
01	600.0	640.0	5.56	5.5	641.6
02	556.4	650.6	4.80	5.0	555.6
03	620.1	630.6	6.79	7.0	752.9
04	552.9	608.8	6.12	6.0	608.8
05	579.9	647.1	6.22	6.0	647.1
06	573.0	562.9	5.88	6.0	562.9
07	522.5	560.6	5.15	5.0	522.5
08	532.4	487.8	5.58	5.5	571.6
09	570.6	600.6	5.48	5.5	599.1
10	501.0	522.9	5.63	5.5	491.2
11	482.9	456.4	4.43	4.5	464.1
12	590.2	616.5	5.43	5.5	643.3
Mean	556.8	582.1	5.59	5.58	588.4
SD	39.1	61.8	0.61	0.61	75.3
% CV	7.0	10.6	10.8	10.9	12.8
Range from	482.9	456.4	4.43	4.5	464.1
to	620.1	650.6	6.79	7.0	752.9

FWIN is the calculated force setting from the Wingate Institute, F = .075 x Weight (kg)

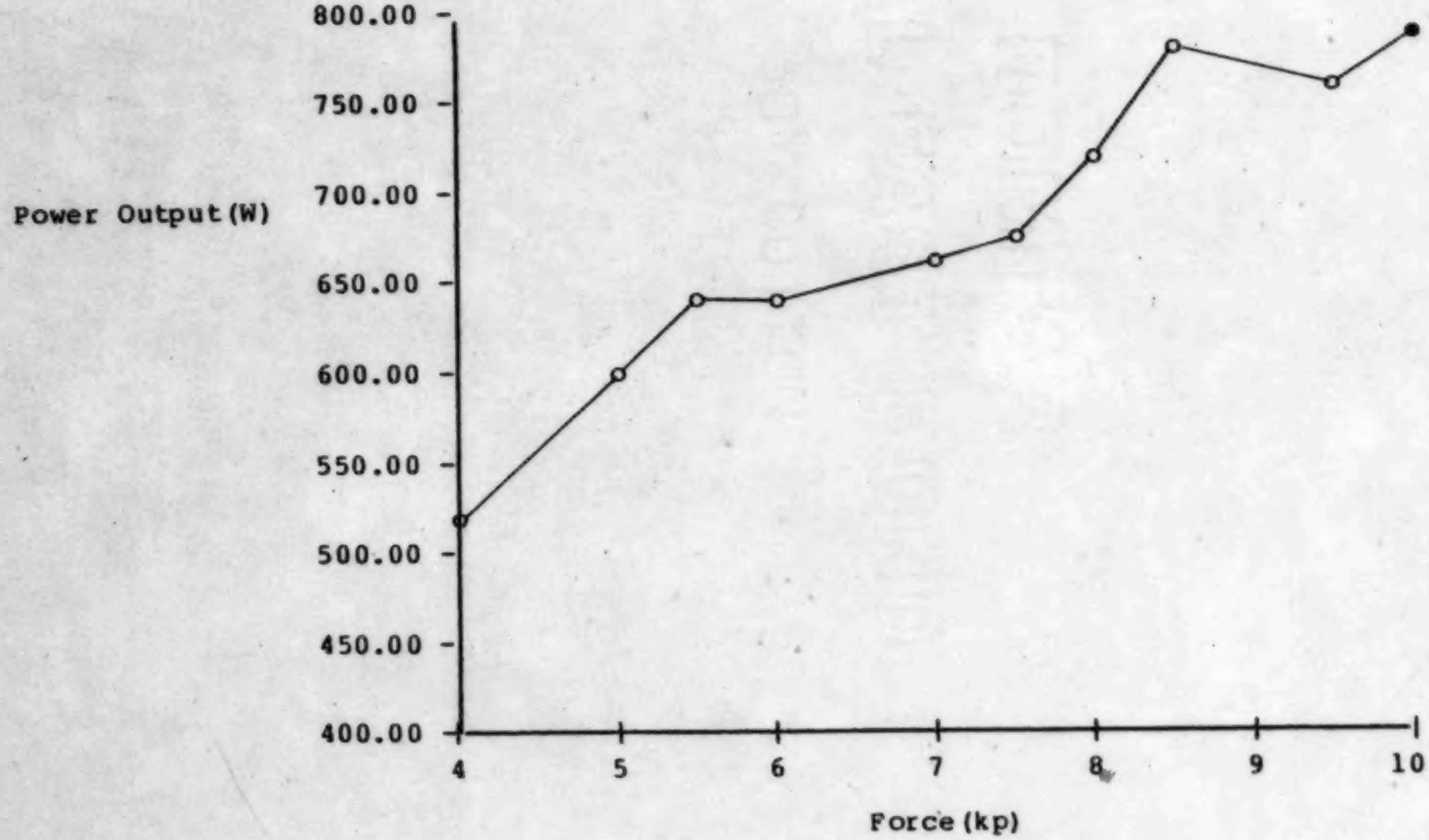
FWINA is the nearest force setting on the bike to FWIN, used to elicit the power output according to the Wingate formula, POWIN

APPENDIX A-III

The Individual Power Curves

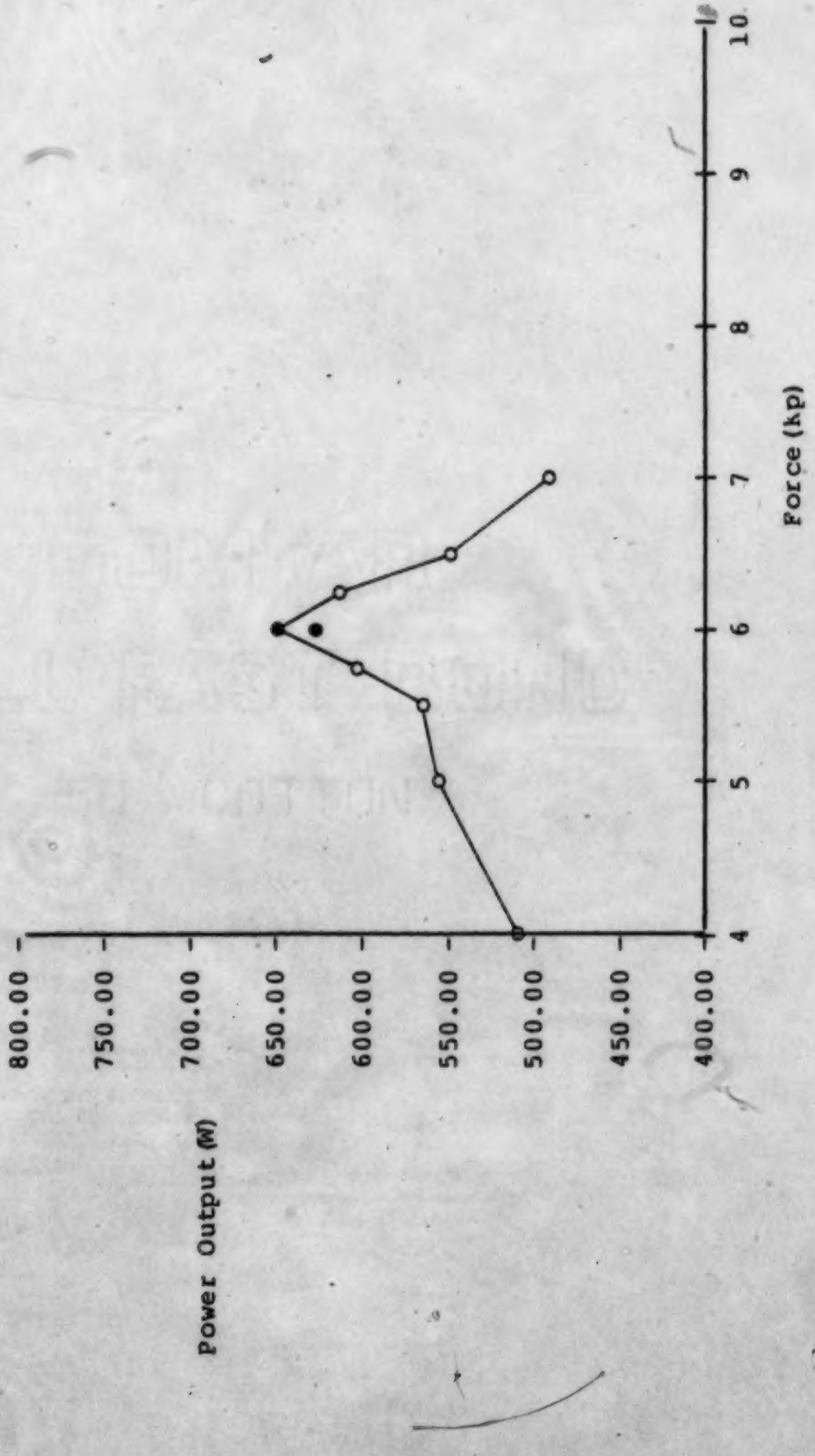
APPENDIX A-III-01

The individual power curve: the relationship of power outputs attained at various force settings (with the point for maximal power output at the true force to elicit maximal power output indicated by the symbol ●) for the individual experimental subject #01.


Power Output (W)
800.00
750.00
700.00
650.00
600.00
550.00
500.00
450.00
400.00
4
5
6
7
8
9
10
Force (kp)

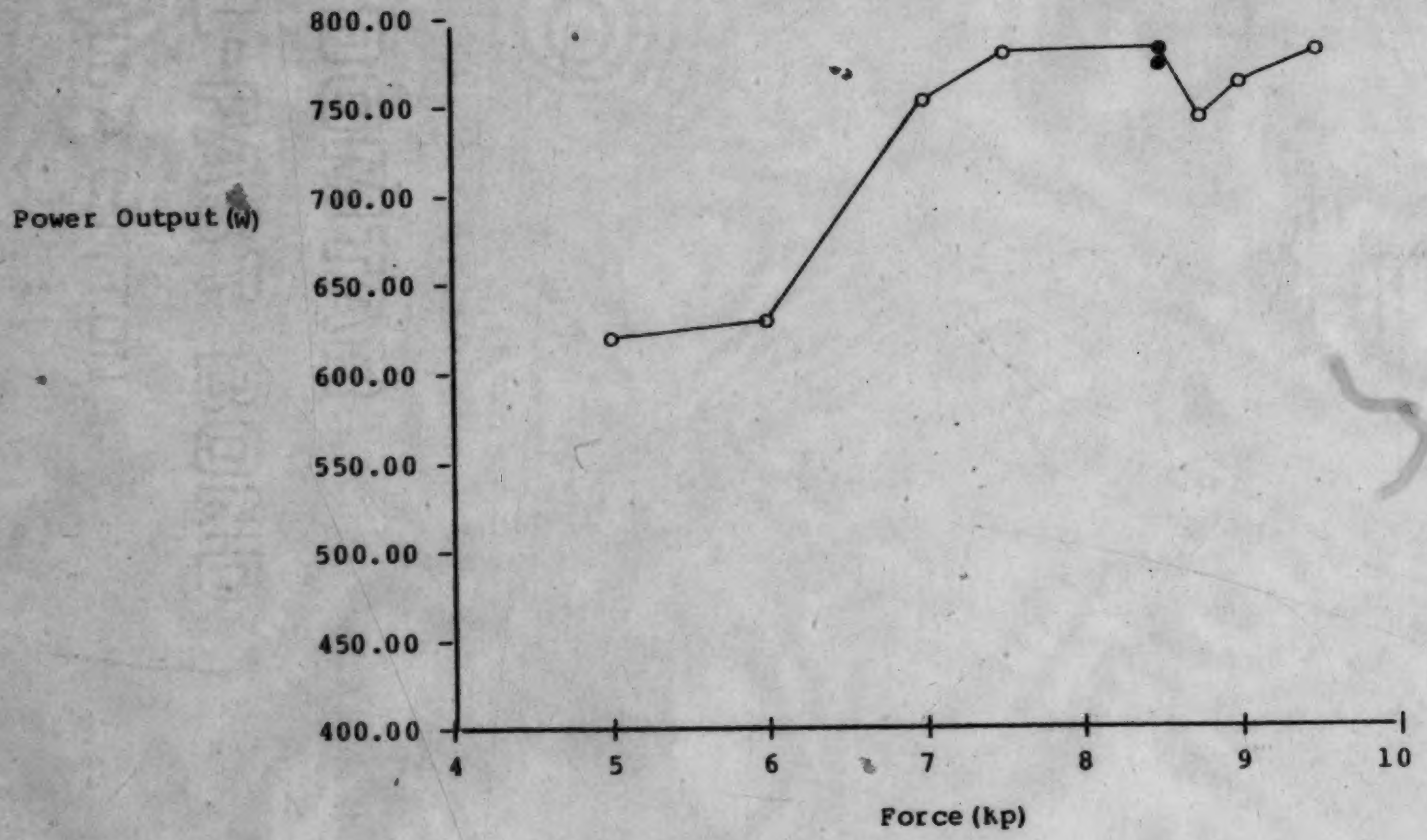
APPENDIX A-III-02

The individual power curve: the relationship of power outputs attained at various force settings (with the point for maximal power output at the true force to elicit maximal power output indicated by the symbol ●) for the individual experimental subject #02.


Power Output (W)
800.00
750.00
700.00
650.00
600.00
550.00
500.00
450.00
400.00
4
5
6
7
8
9
10
Force (kp)

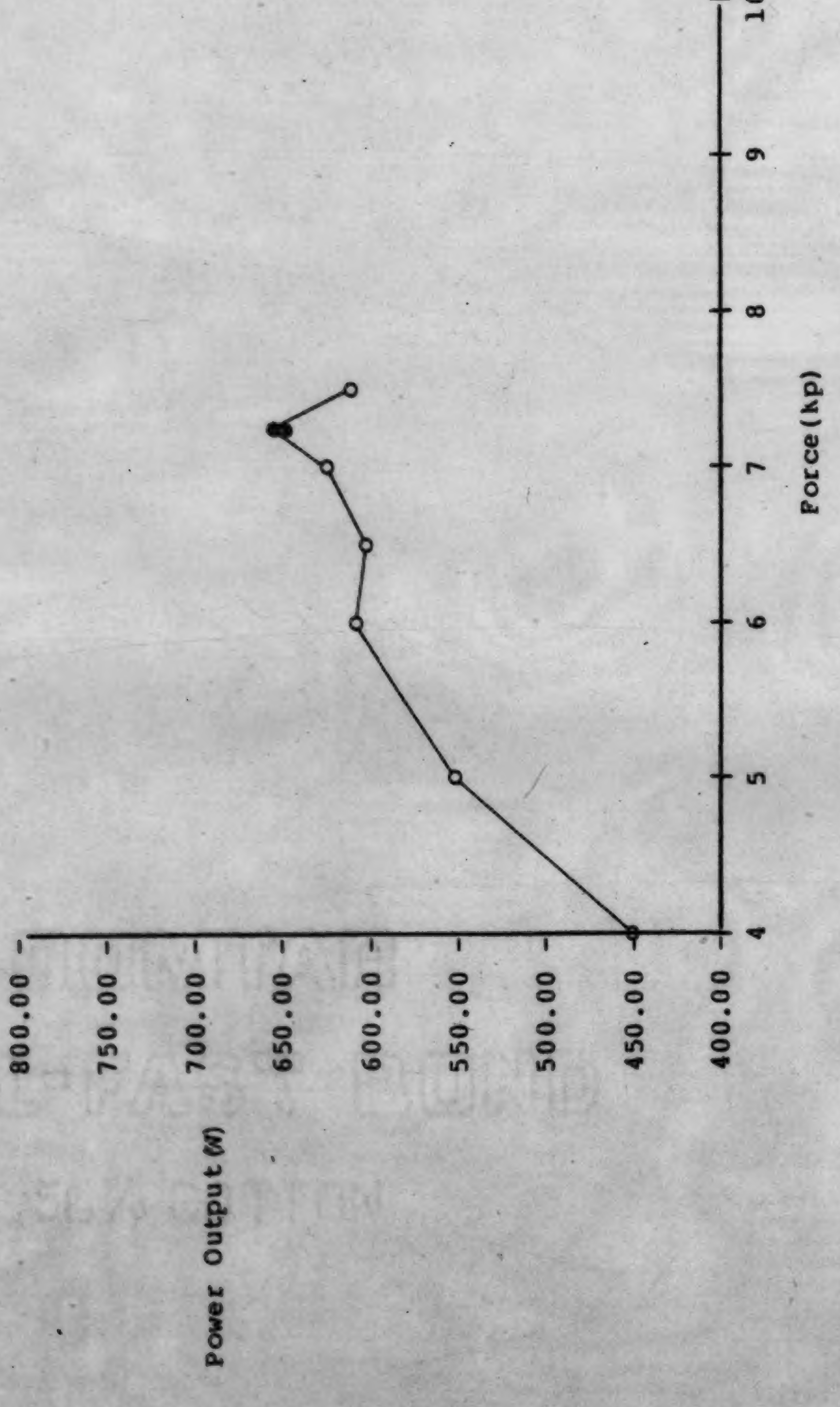
APPENDIX A-III-03

The individual power curve: the relationship of power outputs attained at various force settings (with the point for maximal power output at the true force to elicit maximal power output indicated by the symbol ●) for the individual experimental subject #03.


800.00
750.00
700.00
650.00
600.00
550.00
500.00
450.00
400.00
Power Output (W)
4
5
6
7
8
9
10
Force (kp)

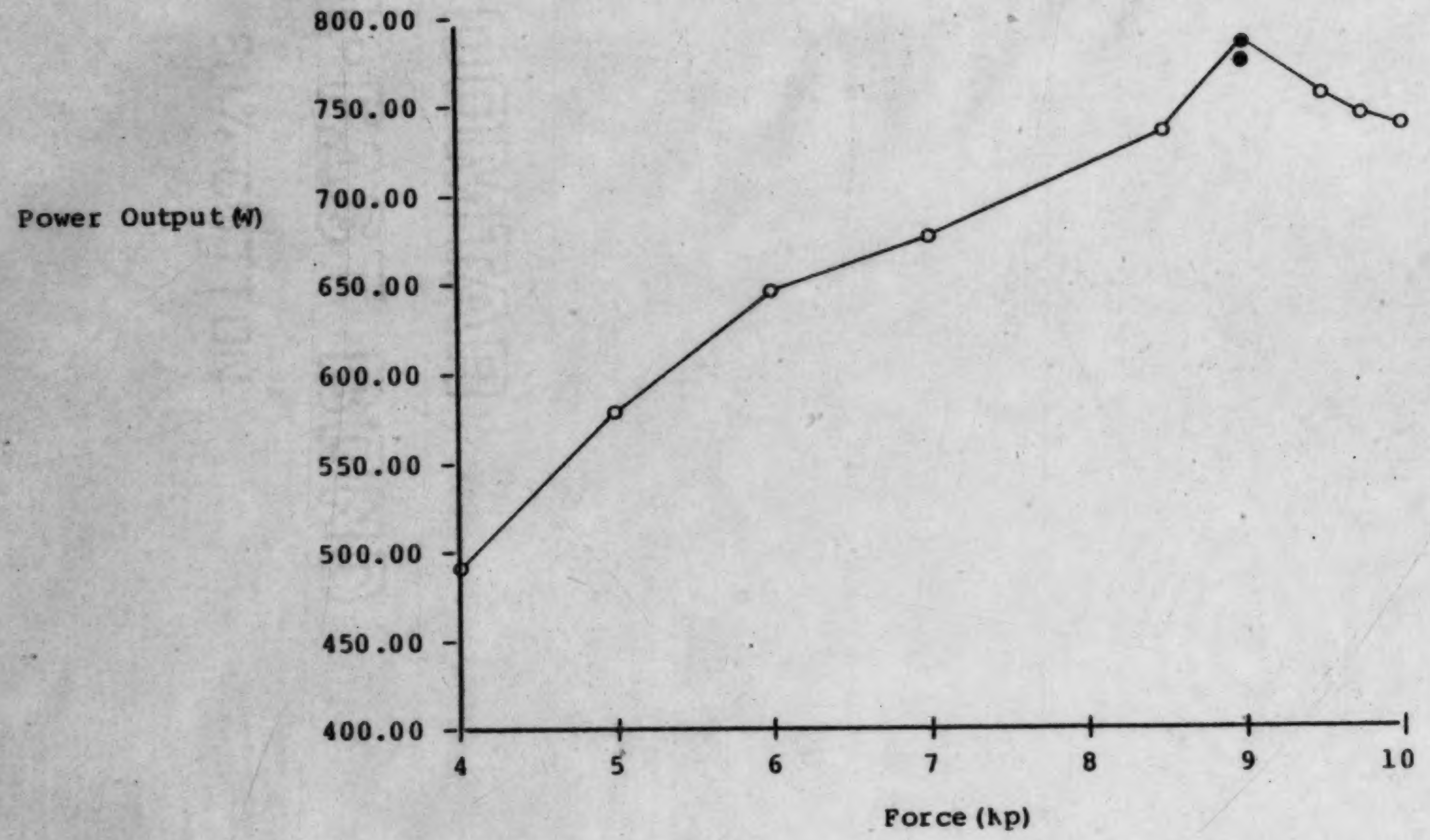
APPENDIX A-III-04

The individual power curve: the relationship of power outputs attained at various force settings (with the point for maximal power output at the true force to elicit maximal power output indicated by the symbol ●) for the individual experimental subject #04.


Power Output (W)
800.00
750.00
700.00
650.00
600.00
550.00
500.00
450.00
400.00
4
5
6
7
8
9
10
Force (kp)

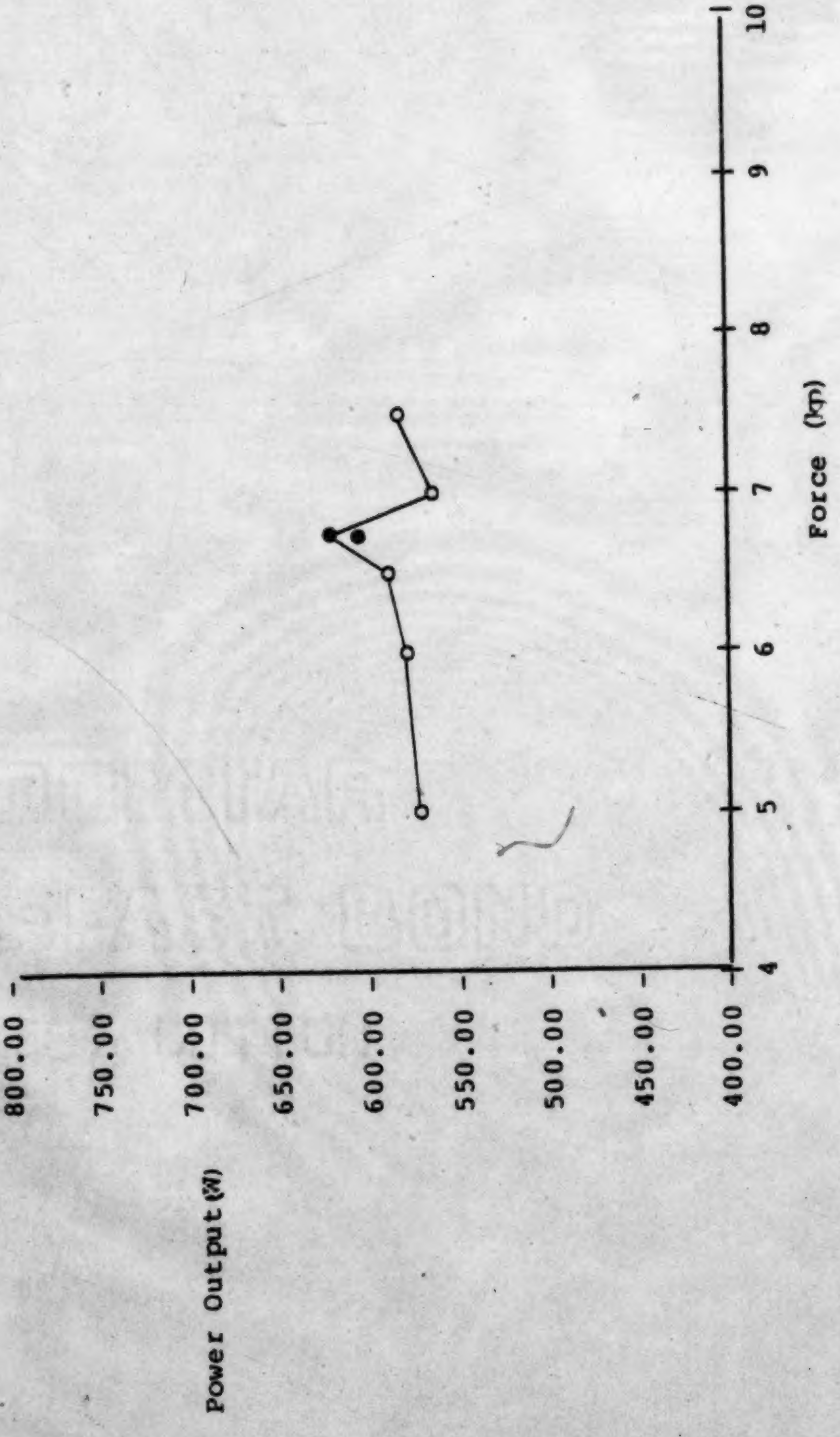
APPENDIX A-III-05

The individual power curve: the relationship of power outputs attained at various force settings (with the point for maximal power output at the true force to elicit maximum power output indicated by the symbol ●) for the individual experimental subject #05.


Power Output (W)
800.00
750.00
700.00
650.00
600.00
550.00
500.00
450.00
400.00
4
5
6
7
8
9
10
Force (kp)

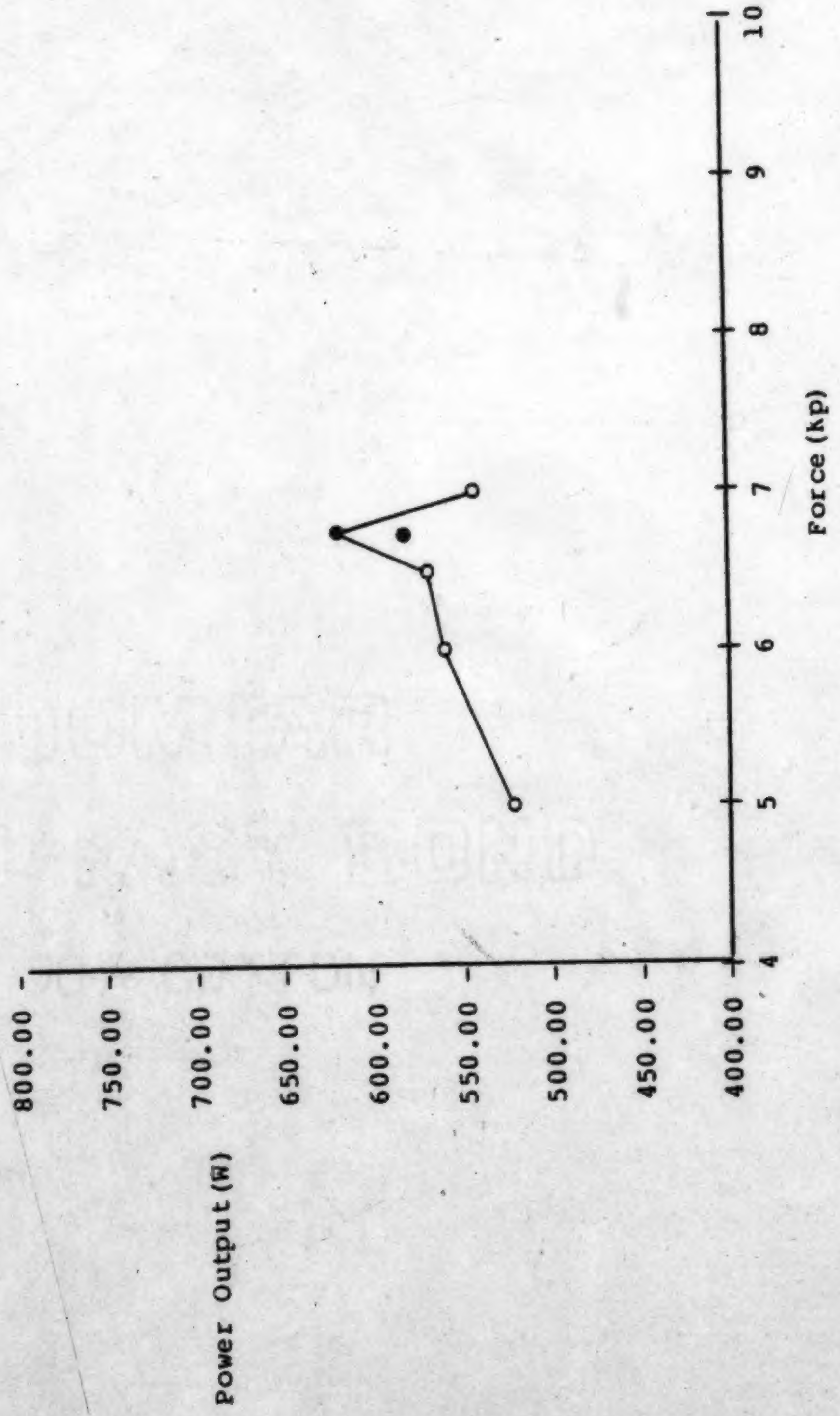
APPENDIX A-III-06

The individual power curve: the relationship of power outputs attained at various force settings (with the point for maximal power output at the true force to elicit maximum power output indicated by the symbol ●) for the individual experimental subject #06.


Power Output (W)
800.00
750.00
700.00
650.00
600.00
550.00
500.00
450.00
400.00
4
5
6
7
8
9
10
Force (kp)

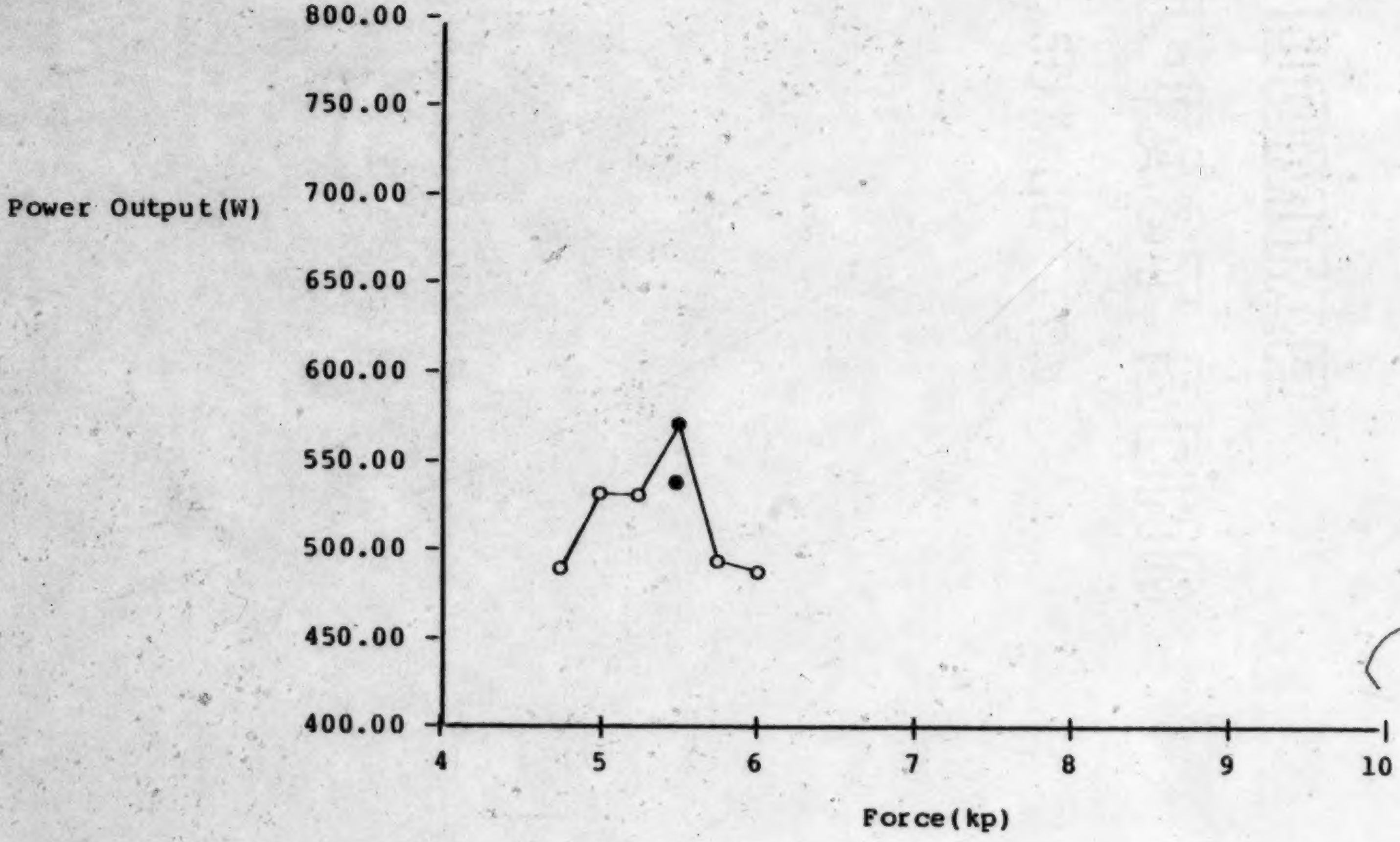
APPENDIX A-III-07

The individual power curve: the relationship of power outputs attained at various force settings (with the point for maximal power output at the true force to elicit maximum power output indicated by the symbol ●) for the individual experimental subject #07.


Power Output (W)
800.00
750.00
700.00
650.00
600.00
550.00
500.00
450.00
400.00
Force (kp)
4
5
6
7
8
9
10

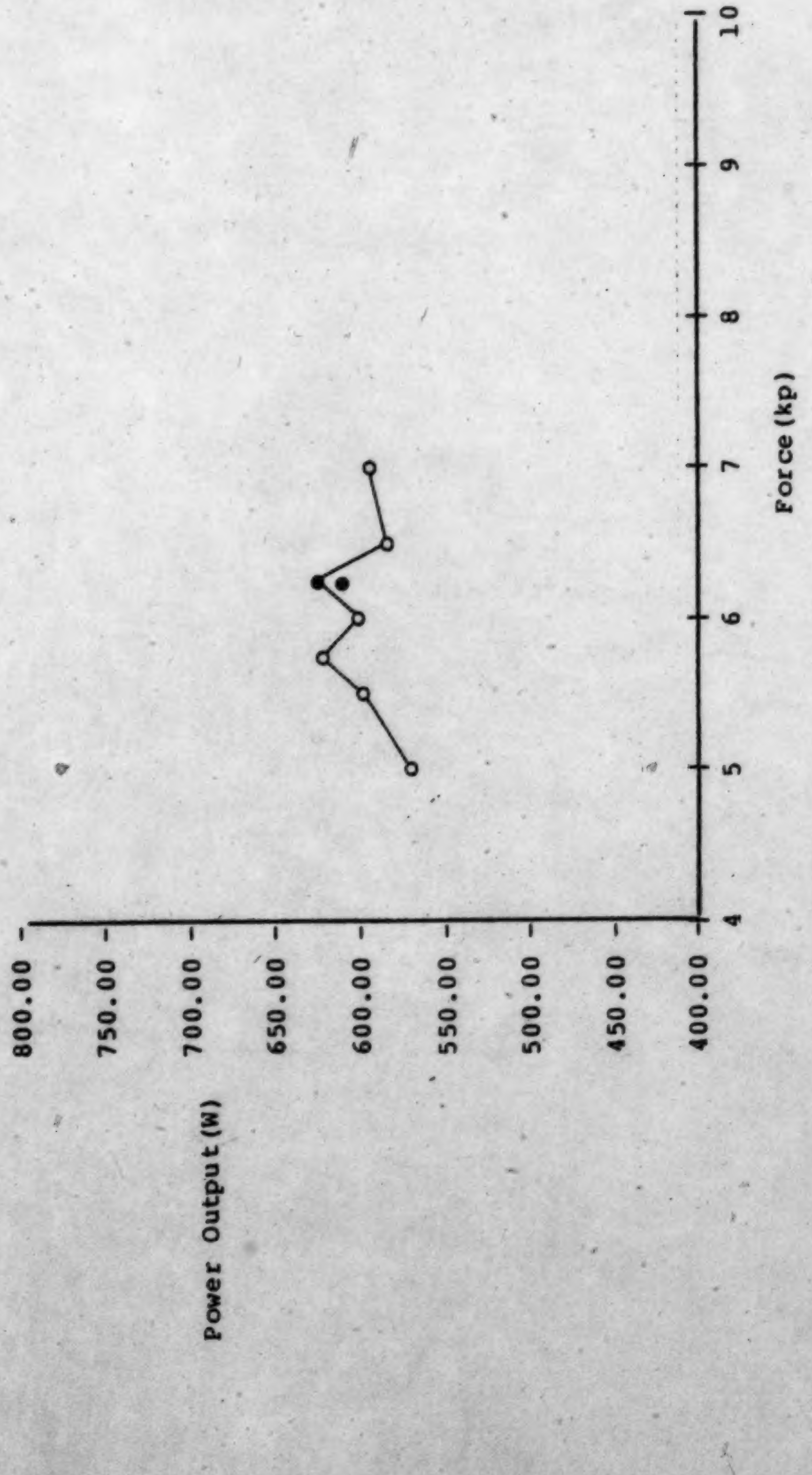
APPENDIX A-III-08

The individual power curve: the relationship of power outputs attained at various force settings (with the point for maximal power output at the true force to elicit maximum power output indicated by the symbol ●) for the individual experimental subject #08.


Power Output (W)
800.00
750.00
700.00
650.00
600.00
550.00
500.00
450.00
400.00
4
5
6
7
8
9
10
Force (kp)

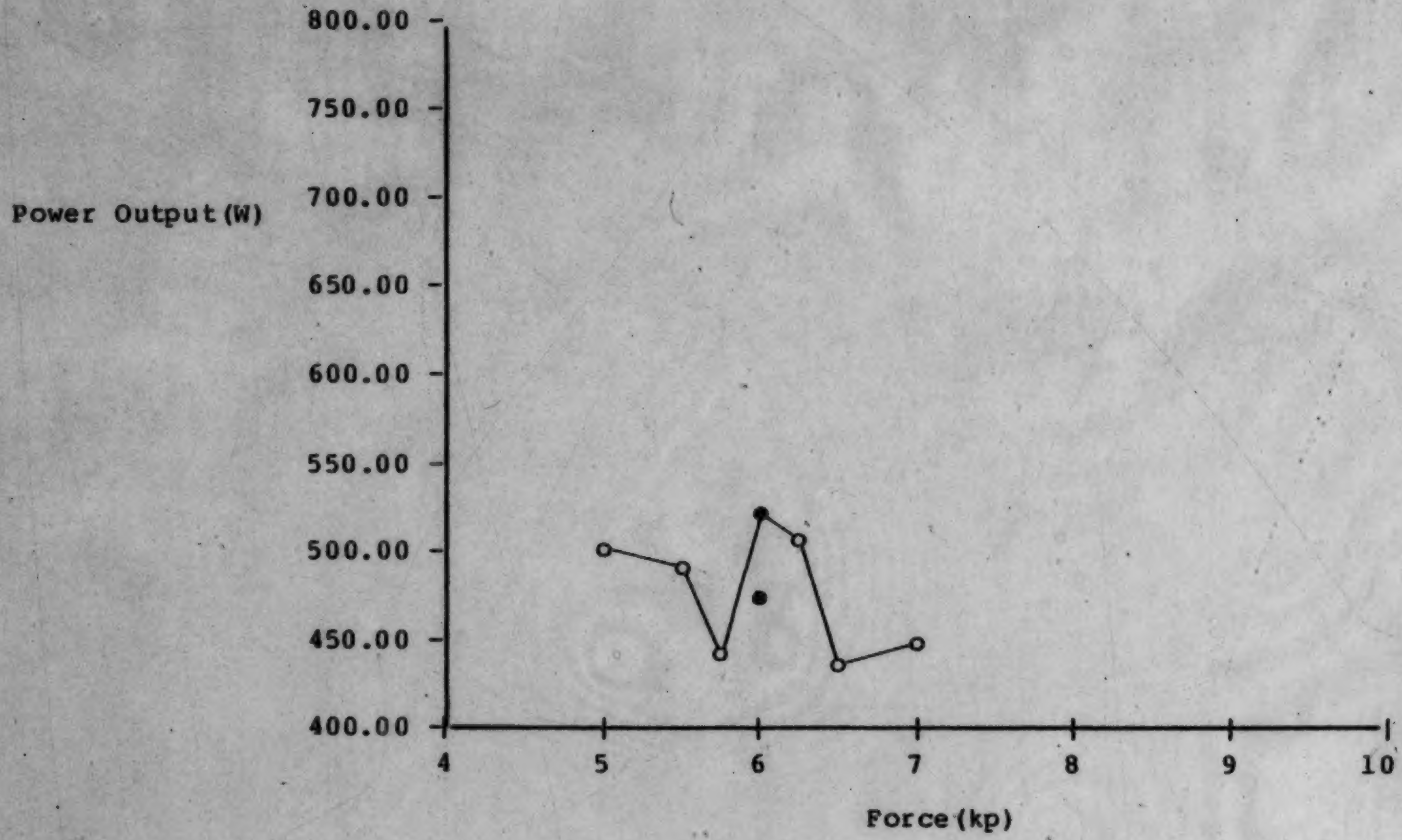
APPENDIX A-III-09

The individual power curve: the relationship of power outputs attained at various force settings (with the point for maximal power output at the true force to elicit maximum power output indicated by the symbol ●) for the individual experimental subject #09.


Power Output (W)
800.00
750.00
700.00
650.00
600.00
550.00
500.00
450.00
400.00
4
5
6
7
8
9
10
Force (kp)

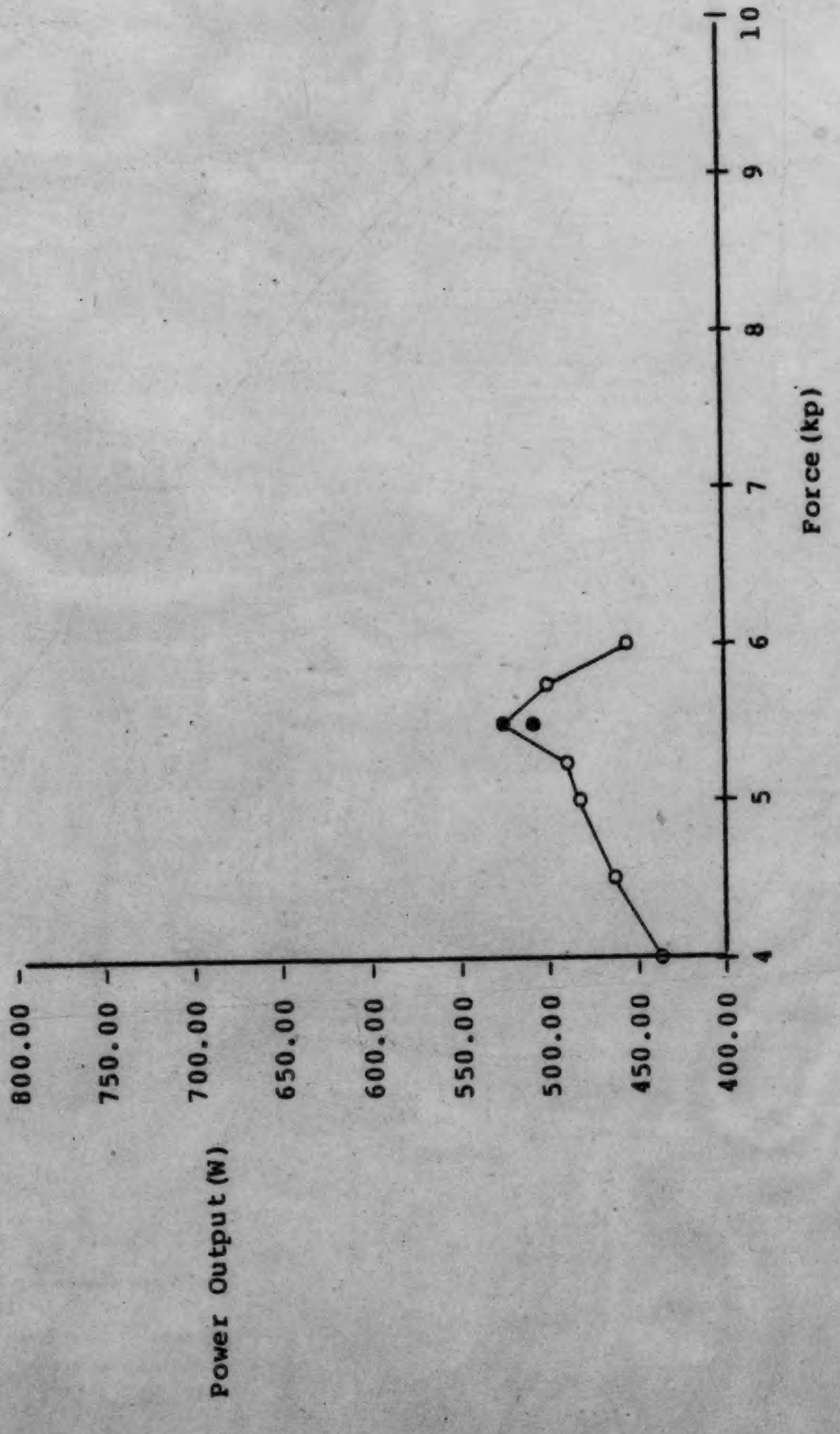
APPENDIX A-III-10

The individual power curve: the relationship of power outputs attained at various force settings (with the point for maximal power output at the true force to elicit maximum power output indicated by the symbol ●) for the individual experimental subject #10.


Power Output(W)
800.00
750.00
700.00
650.00
600.00
550.00
500.00
450.00
400.00
4
5
6
7
8
9
10
Force(kp)

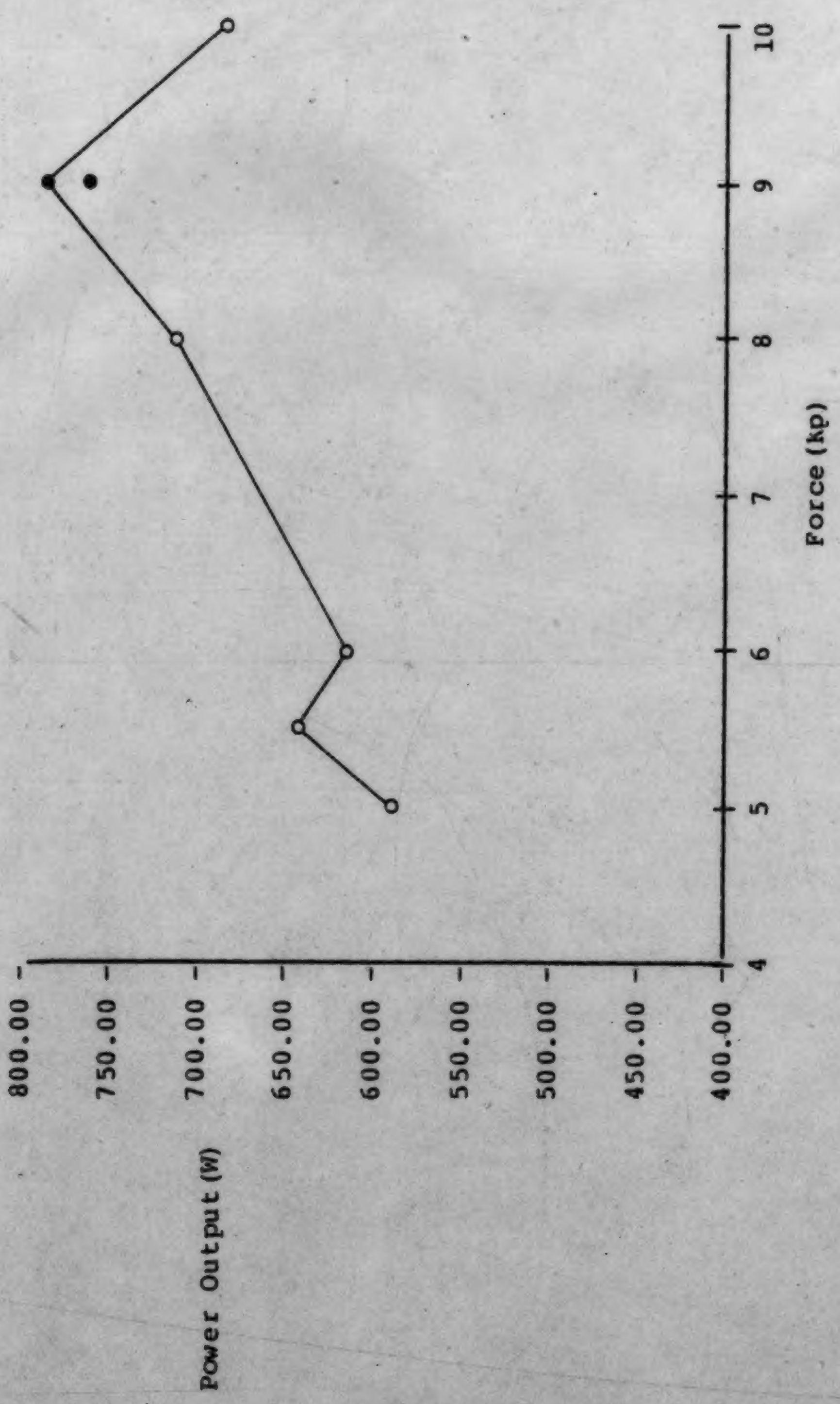
APPENDIX A-III-11

The individual power curve: the relationship of power outputs attained at various force settings (with the point for maximal power output at the true force to elicit maximum power output indicated by the symbol ●) for the individual experimental subject #11.


Power Output (W)
800.00
750.00
700.00
650.00
600.00
550.00
500.00
450.00
400.00
4
5
6
7
8
9
10
Force (kp)

APPENDIX A-III-12

The individual power curve: the relationship of power outputs attained at various force settings (with the point for maximal power output at the true force to elicit maximum power output indicated by the symbol ●) for the individual experimental subject #12.


Power Output (W)
800.00
750.00
700.00
650.00
600.00
550.00
500.00
450.00
400.00
Force (kp)
4
5
6
7
8
9
10

APPENDIX A-IV

Maximal Power of Experimental Subjects

Subject	True FMPO (kp)	MP05s (W)	MP05s/kg (W/kg)	MP030s (W)	MP030s/kg (W/kg)	MV30s (rpm)	Number of Trials
01	10.0	1023.5	13.80	788.2	10.63	80.4	10
02	6.0	787.1	12.30	650.6	10.17	110.6	8
03	8.5	1050.0	11.60	781.7	8.64	93.8	8
04	7.25	852.9	10.45	655.3	8.03	92.2	7
05	9.0	952.9	11.50	785.3	9.47	89.0	9
06	6.75	754.4	9.62	622.7	7.94	94.1	6
07	6.75	806.0	11.73	620.7	9.04	89.5	5
08	5.5	724.7	9.74	571.6	7.68	106.0	6
09	6.25	786.8	10.76	625.6	8.56	102.1	7
10	6.0	698.8	9.31	522.9	6.96	88.9	7
11	5.5	647.1	10.97	526.3	8.92	97.6	7
12	9.0	979.4	13.51	787.9	10.87	89.3	6
Mean	7.21	838.6	11.27	661.6	8.91	94.5	7.2
SD	1.47	127.4	1.38	96.6	1.15	8.4	1.3
% CV	20.4	15.2	12.2	14.6	12.9	8.9	18.8
Range from	5.5	647.1	9.31	522.9	6.96	80.4	5
to	10.0	1050.0	13.80	788.2	10.87	110.6	10

APPENDIX A-V(a)

Physical Characteristics of Olympic Hockey Players (n = 23)

Subject	Age (yrs)	Weight (kg)	Leg Volume (L)	Body Fat (%)
01 G	27	74.5	11.8	9.8
02	27	83.5	14.0	10.9
03	20	80.3	12.7	11.3
04	23	98.3	16.2	11.4
05	20	81.5	13.3	11.1
06	22	82.0	13.1	9.9
07	22	77.1	11.3	9.8
08	20	88.6	14.7	12.0
10	24	75.5	12.4	11.5
11	19	75.1	13.1	11.1
12	21	79.5	13.0	10.3
14	29	81.0	13.1	9.9
15	21	80.1	12.9	10.5
16	21	83.6	13.6	10.5
17	21	95.0	15.8	11.2
18	23	86.3	14.4	11.5
19	19	74.0	10.6	10.3
20	21	80.6	12.7	9.5
21	24	81.3	13.0	9.9
22	21	80.9	13.1	10.4
23	22	77.2	11.5	11.3
25	19	78.9	13.6	10.0
30 G	23	69.5	11.7	10.4
Mean	22.1	81.1	13.1	10.6
SD	2.59	6.33	1.30	0.67
% CV	11.7	7.8	9.9	6.5
Range from	19	69.5	10.6	9.5
to	29	98.3	16.2	12.0

G goalie

APPENDIX A-V(b)

Maximal Power of Olympic Hockey Players (n = 23)

Subject	Estimated FMPO (kp)	MP05s (W)	MP05s/kg (W/kg)	MP030s (W)	MP030s/kg (W/kg)	MV30s (rpm)
01 G	8.41	791.5	10.63	675.3	9.06	81.9
02	11.12*	1058.8	12.68	833.3	9.98	85.0
03	9.06	906.0	11.28	789.6	9.83	88.9
04	12.59*	1023.5	10.41	853.0	8.68	87.0
05	10.07*	1023.5	12.56	849.0	10.42	86.6
06	9.54	993.3	12.11	868.9	10.60	92.9
07	6.80	819.4	10.63	717.5	9.31	107.7
08	11.50*	1023.5	11.55	842.2	9.51	85.1
10	9.46	990.5	13.12	763.3	10.11	82.3
11	11.03*	752.9	10.03	691.2	9.20	70.5
12	9.87	888.3	11.17	743.2	9.35	76.8
14	9.76	878.4	10.84	700.4	8.65	73.2
15	9.53	964.2	12.04	794.2	9.91	85.0
16	10.25*	988.2	11.82	808.8	9.68	82.5
17	12.45*	864.7	9.10	714.7	7.52	72.9
18	11.36*	1147.1	13.29	891.2	10.33	90.9
19	5.98	932.2	12.60	740.5	10.01	126.3
20	9.00	1074.7	13.33	915.0	11.35	103.7
21	9.48	981.5	12.07	835.6	10.28	89.9
22	9.78	966.5	11.95	752.7	9.30	78.5
23	7.20	855.5	11.08	691.8	8.96	98.0
25	11.27*	952.9	12.08	716.7	9.08	73.1
30 G	9.27	812.5	11.69	638.9	9.19	70.3
Mean	9.77	943.0	11.65	775.1	9.58	86.5
SD	1.61	96.7	1.05	74.6	0.78	12.9
% CV	16.5	10.3	9.0	9.6	8.16	8.1
Range from	5.98	752.9	9.10	638.9	7.52	70.3
to	12.59	1147.1	13.33	915.0	11.35	126.3

G goalie
* 10.0 kp setting used

APPENDIX B

APPENDIX B-I Pairwise Dependent t-Test for Difference between MPO30s and PO at mean FMPO

APPENDIX B-II Pairwise Dependent t-Test for Difference between MPO30s and POWIN

APPENDIX B-I

Pairwise-Dependent t-Test for Difference Between MPO30s and PO at Mean FMPO = 7.21 kp (n = 12)

	MPO30s (W)	PO at Mean FMPO (W)	Difference (W)
	788.2	662.3	125.9
	650.6	492.1	158.5
	781.7	752.9	28.8
	655.3	655.3	0
	785.3	678.0	107.3
	605.5	564.8	40.7
	579.0	543.5	35.5
	535.4	487.8	47.6
	625.6	593.6	32.0
	522.9	448.8	74.1
	505.8	456.4	49.4
	761.5	713.7	47.8
Mean	649.7	587.4	62.3
SD	102.0	99.8	45.9
% CV	15.7	17.0	73.7
Range from	505.8	448.8	0
to	788.2	752.9	158.5

To test $H_o : u_d = 0$

vs. $H_1 : u_d > 0$

where the sample values are pairwise-dependent. If the population of all potential differences is normal, then:

$$t = \frac{\bar{d} - 0}{SD/\sqrt{n}}$$

where n = number of pairs of observations

$$= \frac{62.3}{45.9/\sqrt{12}}$$

$$= 4.70$$

and reject H_o if:

$t > \text{critical } t$ at $\alpha = .05$ for 11 degrees of freedom

> 1.796

There was a significant difference ($p < .05$) between MPO30s and the PO at mean FMPO.

APPENDIX B-II

Pairwise-Dependent t-Test for Difference Between MPO30s and POWIN

	MPO30s (W)	PO at Mean FMPO (W)	Difference (W)
	788.2	641.6	146.6
	650.6	556.4	94.2
	781.7	752.9	28.8
	655.3	608.8	46.5
	785.3	647.1	138.2
	605.5	562.9	42.6
	579.0	522.5	56.5
	535.4	571.6	-36.2
	625.6	599.1	26.5
	522.9	491.2	31.7
	505.8	464.1	41.7
	761.5	643.3	118.2
Mean	649.7	588.5	61.3
SD	102.0	53.2	53.2
%CV	15.7	9.0	86.8
Range from	505.8	464.1	-36.2
to	788.2	752.9	146.6

To test $H_o : u_d = 0$

vs. $H_1 : u_d > 0$

where the sample values are pairwise-dependent. If the population of all potential differences is normal, then:

$$t = \frac{\bar{d} - 0}{SD/\sqrt{n}}$$

where n = number of pairs of observations

$$= \frac{61.3}{53.2/\sqrt{12}}$$

$$= 3.99$$

and reject H_o if:

$t > \text{critical } t \text{ at } \alpha = .05$ for 11 degrees of freedom

> 1.796

There was a significant difference ($p < .05$) between MPO30s and the PO at mean FMPO.

APPENDIX C

Reliability of Maximal Power Output for the Experimental Subjects

APPENDIX C

Reliability of Maximal Power Output for Experimental Subjects (n = 11)

Subject	Test MP05s (W)	Retest MP05s (W)	Test MP030s (W)	Retest MP030s (W)
* 01	1023.5	-	788.2	-
02	787.1	741.2	650.6	625.9
03	1050.0	1065.0	781.7	777.5
04	852.9	844.4	655.3	651.1
05	952.9	968.8	785.3	774.7
06	766.3	754.4	605.5	622.7
07	754.4	806.0	579.0	620.7
08	637.4	724.7	535.4	571.6
09	786.8	672.8	625.6	609.1
10	698.8	634.4	522.9	472.4
11	663.2	647.1	505.8	526.3
12	915.9	979.4	761.5	787.9
Mean =	806.0	801.6	637.1	640.0
Difference of Means	4.4		2.9	
SD	120.9	140.8	97.2	98.4
% CV	15.0	17.6	15.3	15.4
	r = 0.912		r = 0.962	
	Slope >0 ($p<.05$)		Slope >0 ($p<.05$)	

* missing data, row entry omitted in above calculations

APPENDIX D

APPENDIX D-I	Matrix of Correlation Coefficients for Regression Variables
APPENDIX D-II	Summary of Stepwise Multiple Regression Analyses
APPENDIX D-III	A Conservative Estimate of R^2

APPENDIX D-I

Matrix of Correlation Coefficients for Regression Variables

	1	2	3	4	5	6	7	8	9	10	11	12	13
1. Age													
2. Height	0.557												
3. Weight	0.101	0.396											
4. Fat	0.237	0.334	0.483										
5. Pondural Index	-0.309	-0.417	0.659	0.193									
6. Leg Volume	-0.076	0.181	0.921	0.332	0.750								
7. Leg Length	-0.231	0.533	0.044	0.129	-0.454	-0.101							
8. Thigh Girth	-0.320	0.087	0.856	0.431	0.772	0.835	0.082						
9. Calf Girth	-0.153	0.141	0.887	0.463	0.755	0.879	-0.011	0.923					
10. Thigh Skinfold	-0.272	-0.302	0.613	0.313	0.833	0.710	-0.304	0.719	0.804				
11. Calf Skinfold	-0.002	-0.518	0.070	0.145	0.516	0.105	-0.654	0.179	0.028	0.233			
12. PO5kp	0.033	0.158	0.648	0.255	0.549	0.755	-0.210	0.671	0.682	0.608	0.023		
13. PO6kp	-0.118	-0.039	0.442	0.079	0.490	0.649	-0.375	0.527	0.580	0.654	0.118	0.816	
14. FMPO (dependent variable)	-0.1249	-0.137	0.506	-0.082	0.642	0.743	-0.342	0.543	0.581	0.549	0.133	0.774	0.704

APPENDIX D-II

Summary of Stepwise Multiple Regression Analyses

Dependent Variable is FMPO.
Probability to enter and remove independent variable is 0.05.

Step number$^+$		A	B1	B2
Variable entered		#12. PO5kp	#6. Leg volume	
Degrees of freedom	total	11	11	11
	regression	1	1	2
	residual	10	10	9
Overall F		14.9592	12.2917	14.4079
Probability		0.0031	0.0057	0.0016
Multiple correlation		0.7742	0.7426	0.8729
Standard deviation of residuals		1.0202	1.0795	0.8289
Partial B		0.0291	12.2917	2.1124, -0.2151
Probability		0.0031	0.0057	0.0018, 0.0200
Constant term in equation		-9.0166	-2.4179	-0.4914
Partial correlation coefficients of variables not entered	1	0.2376	0.1028	0.3036
	2	0.4149	0.4124	0.0036
	3	0.0080	0.6852	-
	4	0.4549	0.5191	0.2940
	5	0.4098	0.1922	0.1473
	6	0.3807	-	-
	7	0.2890	0.3997	0.2287
	8	0.0499	0.2090	0.0999
	9	0.1144	0.2250	0.0905
	10	0.1552	0.0458	0.0811
	11	0.1802	0.0829	0.0497
	12	-	*	*
	13	0.1986	*	*
Variables yet to enter		no	yes	no

APPENDIX D-II (continued)

Note * P05kp and P06kp not entered in independent variable list for series B regression.

+ regression series A yielded only one significant independent variable. P05kp and series B, without independent pretest variables, P05kp and P06kp, included, yielded only two significant anthropometric independent variables.

APPENDIX D-III

A Conservative Estimate of R^2

The formula for the conservative estimate of R^2 was proposed by Kerlinger (1973):

$$R_c^2 = 1 - (1 - R^2)\,\frac{N - 1}{N - n}$$

Where R_c^2 is R^2 corrected for small sample size

N is size of sample

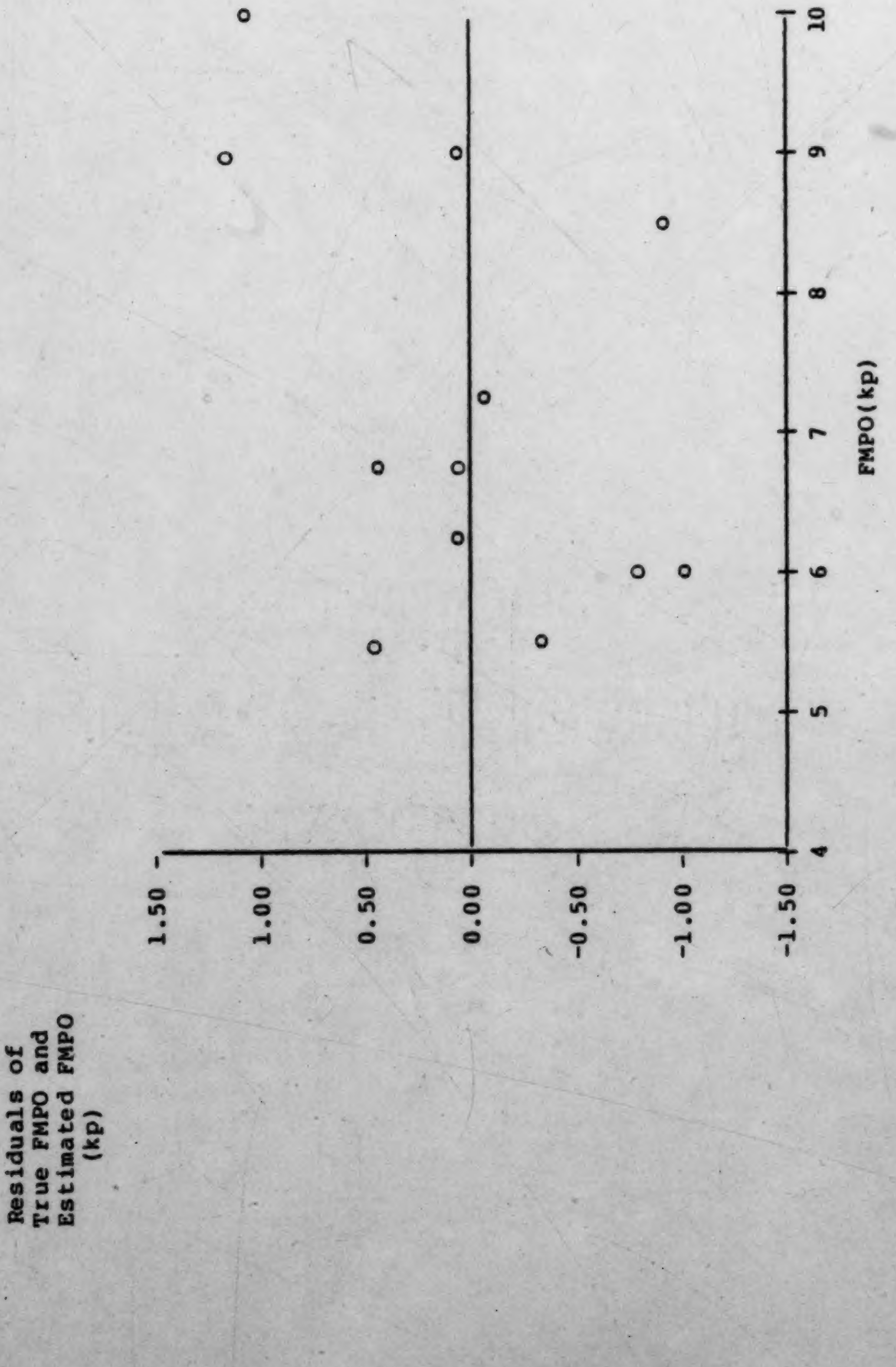
n is total number of variables in the analysis

APPENDIX E

APPENDIX E-I	Distribution of FMPO Residuals Versus True FMPO
APPENDIX E-II	Distribution of FMPO Residuals Versus Leg Volume
APPENDIX E-III	Distribution of FMPO Residuals Versus Weight
APPENDIX E-IV	Distribution of FMPO Residuals Versus PO5kp
APPENDIX E-V	Unidimensional Scatter Plots of FMPO Residuals as a Test of Normality
APPENDIX E-IV	Comparison of True and Estimated FMPO and MPO303

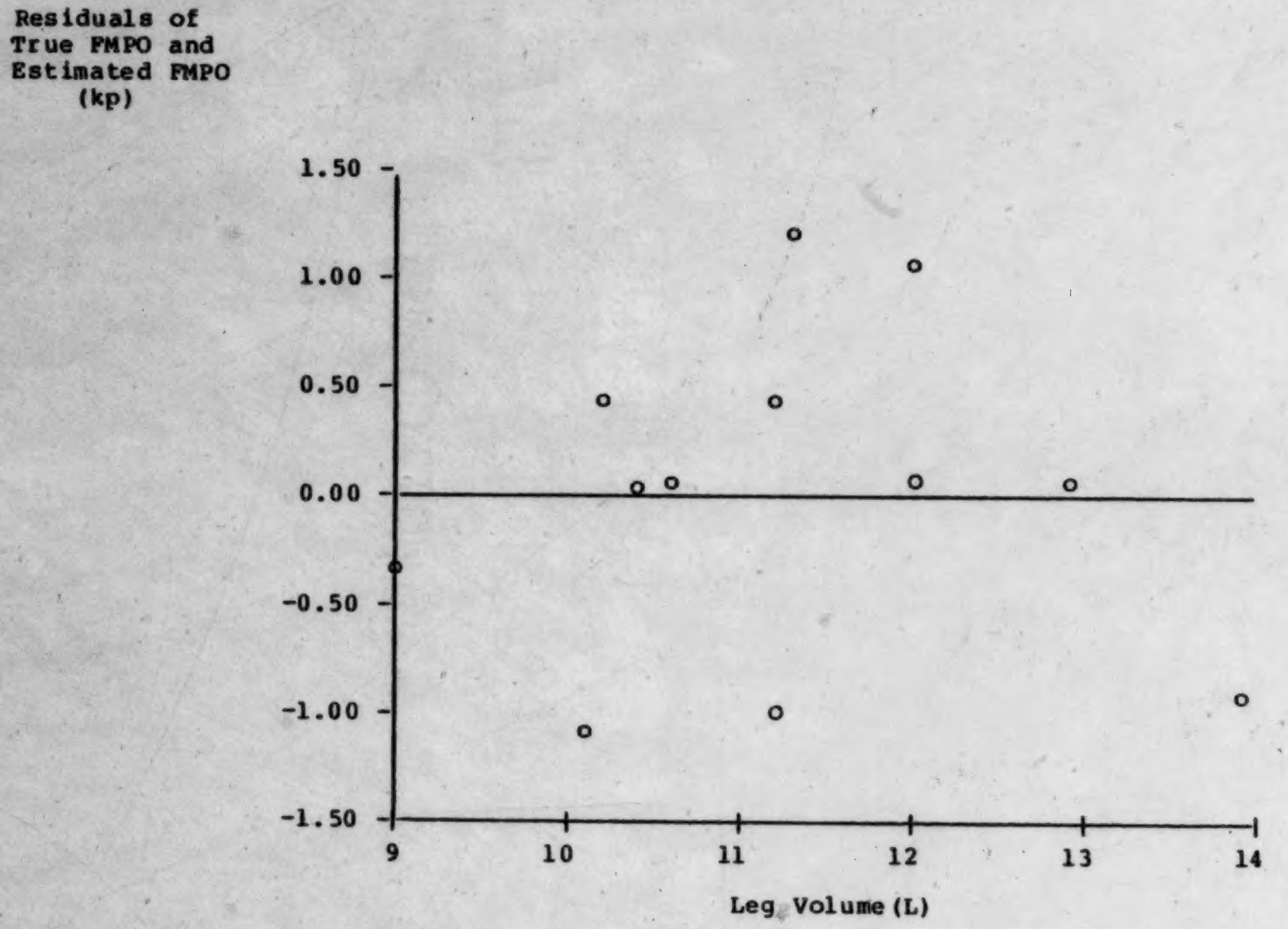
APPENDIX E-I

Distribution of the residuals of true and estimated force to elicit maximal power output versus true force to elicit maximal power output for the experimental group (n=12)


Residuals of
True FMPO and
Estimated FMPO
(kp)
1.50
1.00
0.50
0.00
-0.50
-1.00
-1.50
4
5
6
7
8
9
10
FMPO(kp)

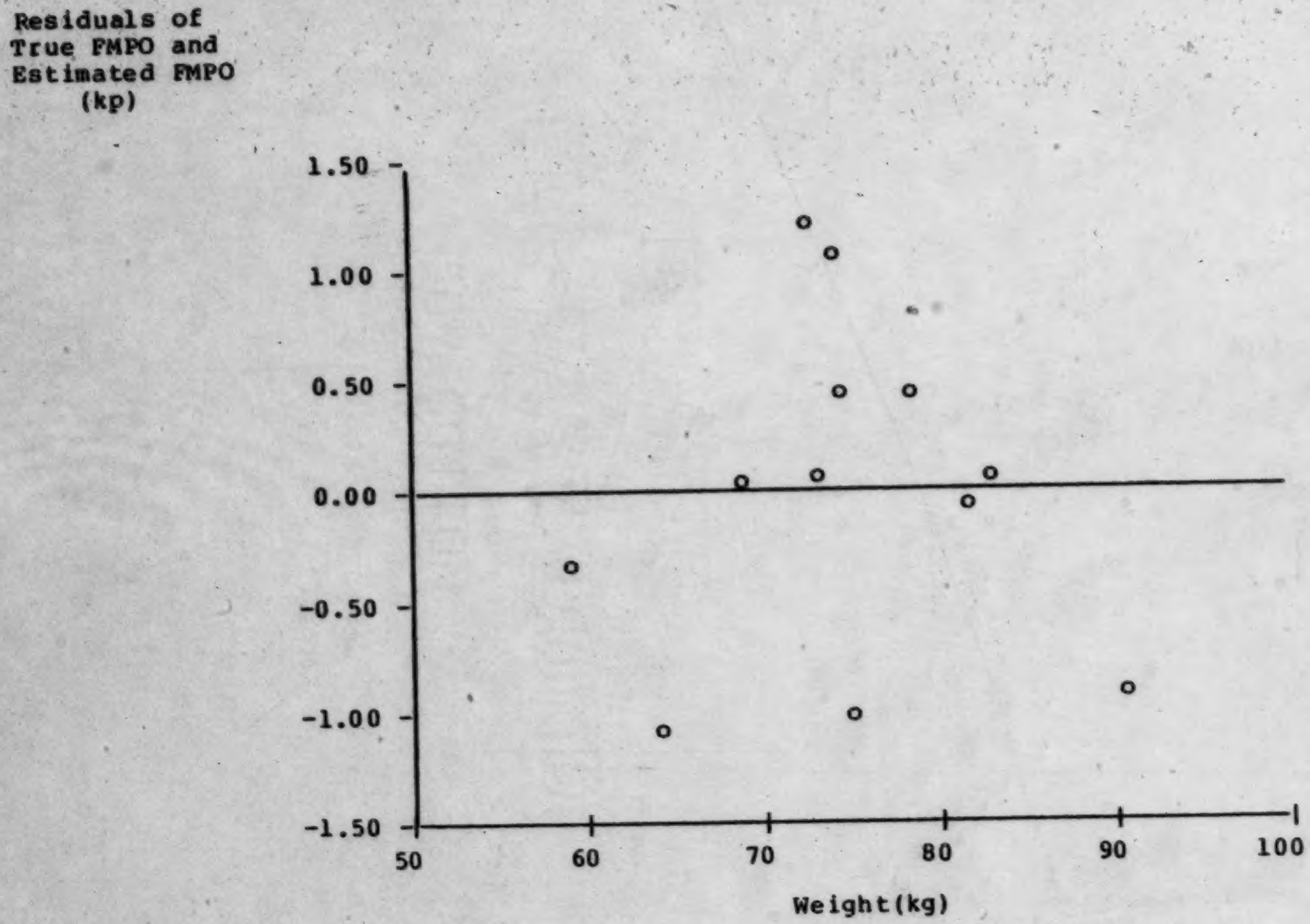
APPENDIX E-II

Distribution of residuals of true and
estimated force to elicit maximal power output
versus leg volume for experimental group (n=12)


Residuals of
True FMPO and
Estimated FMPO
(kp)
1.50
1.00
0.50
0.00
-0.50
-1.00
-1.50
9
10
11
12
13
14
Leg Volume (L)

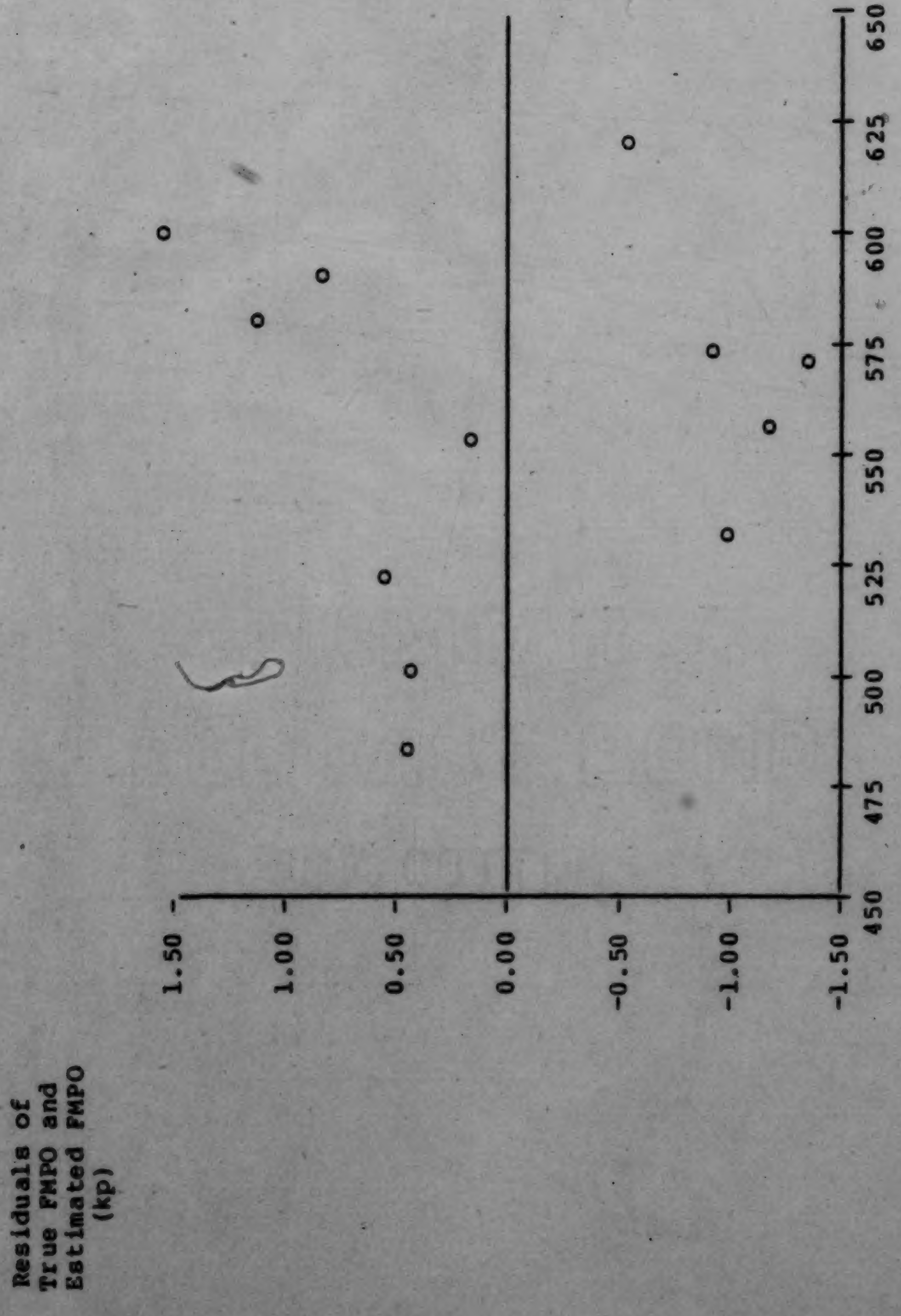
APPENDIX E-III

Distribution of residuals of true and
estimated force to elicit maximal power output
versus body weight for experimental group (n=12)


Residuals of
True FMPO and
Estimated FMPO
(kp)
1.50
1.00
0.50
0.00
-0.50
-1.00
-1.50
50
60
70
80
90
100
Weight(kg)

APPENDIX E-IV

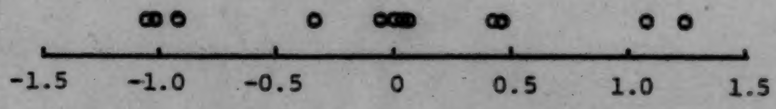
Distribution of the residuals of true and
estimated force to elicit maximal power output
versus power output at 5 kp for 30s
for the experimental group (n=12)


Residuals of
True FMPO and
Estimated FMPO
(kp)
1.50
1.00
0.50
0.00
-0.50
-1.00
-1.50
450
475
500
525
550
575
600
625
650
PO30s at 5 kp (W)

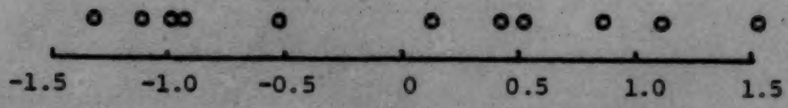
APPENDIX E-V

Unidimensional scatter plots of the residual errors of FMPO as a test of normality (Kleinbaum and Kupper, 1978).

(a) Based on anthropometric data



(b) Based on pretest data



APPENDIX E-VI

Comparison of True and Estimated FMPO and MPO30s

Anthropometrically

Subject Number	Estimated FMPO[1]	FMPO (kp)	Difference	MPO30s (W)	PO at FMPO[1]	Difference
1	10.0	8.5	+1.5	788.2	780.0	+8.2
2	6.0	7.0	-1.0	650.6	492.1	+158.5
3	8.5	9.5	-1.0	781.7	780.5	1.2
4	7.25	7.25	0	655.3	655.3	0
5	9.0	9.0	0	785.3	785.3	0
6	6.75	6.5	+0.25	622.7	589.5	33.2
7	6.75	6.75	0	620.7	620.7	0
8	5.5	5.0	+0.5	571.6	532.4	39.2
9	6.95	6.25	0	625.6	625.6	0
10	6.0	7.0	-1.0	522.9	448.8	14.1
11	5.5	5.75	-0.25	526.3	501.2	25.1
12	9.0	8.0	+1.0	787.9	713.7	74.2
Mean	7.21	7.21	1.388	661.6	627.1	34.5
SD	1.47	1.27	0.743	96.6	114.2	45.8
Range from	5.5	5.0	0	522.9	448.8	0
to	10.0	9.5	1.5	788.2	785.3	158.5